This is a digital copy of a book that was preserved for generations on library shelves before it was carefully scanned by Google as part of a project to make the world's books discoverable online.

It has survived long enough for the copyright to expire and the book to enter the public domain. A public domain book is one that was never subject to copyright or whose legal copyright term has expired. Whether a book is in the public domain may vary country to country. Public domain books are our gateways to the past, representing a wealth of history, culture and knowledge that's often difficult to discover.

Marks, notations and other marginalia present in the original volume will appear in this file - a reminder of this book's long journey from the publisher to a library and finally to you.

Usage guidelines

Google is proud to partner with libraries to digitize public domain materials and make them widely accessible. Public domain books belong to the public and we are merely their custodians. Nevertheless, this work is expensive, so in order to keep providing this resource, we have taken steps to prevent abuse by commercial parties, including placing technical restrictions on automated querying.

We also ask that you:

+ *Make non-commercial use of the files* We designed Google Book Search for use by individuals, and we request that you use these files for personal, non-commercial purposes.

+ *Refrain from automated querying* Do not send automated queries of any sort to Google's system: If you are conducting research on machine translation, optical character recognition or other areas where access to a large amount of text is helpful, please contact us. We encourage the use of public domain materials for these purposes and may be able to help.

+ *Maintain attribution* The Google "watermark" you see on each file is essential for informing people about this project and helping them find additional materials through Google Book Search. Please do not remove it.

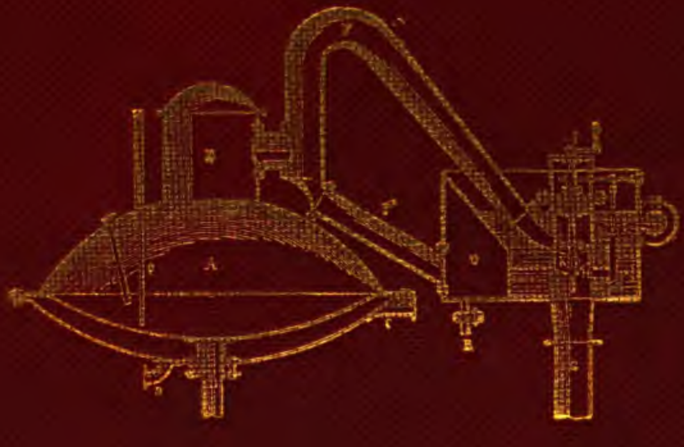
+ *Keep it legal* Whatever your use, remember that you are responsible for ensuring that what you are doing is legal. Do not assume that just because we believe a book is in the public domain for users in the United States, that the work is also in the public domain for users in other countries. Whether a book is still in copyright varies from country to country, and we can't offer guidance on whether any specific use of any specific book is allowed. Please do not assume that a book's appearance in Google Book Search means it can be used in any manner anywhere in the world. Copyright infringement liability can be quite severe.

About Google Book Search

Google's mission is to organize the world's information and to make it universally accessible and useful. Google Book Search helps readers discover the world's books while helping authors and publishers reach new audiences. You can search through the full text of this book on the web at `http://books.google.com/`

EVAPORATION

IN THE CANE AND THE BEET SUGAR FACTORY



EDWARD KOPPESCHAAR

GIFT

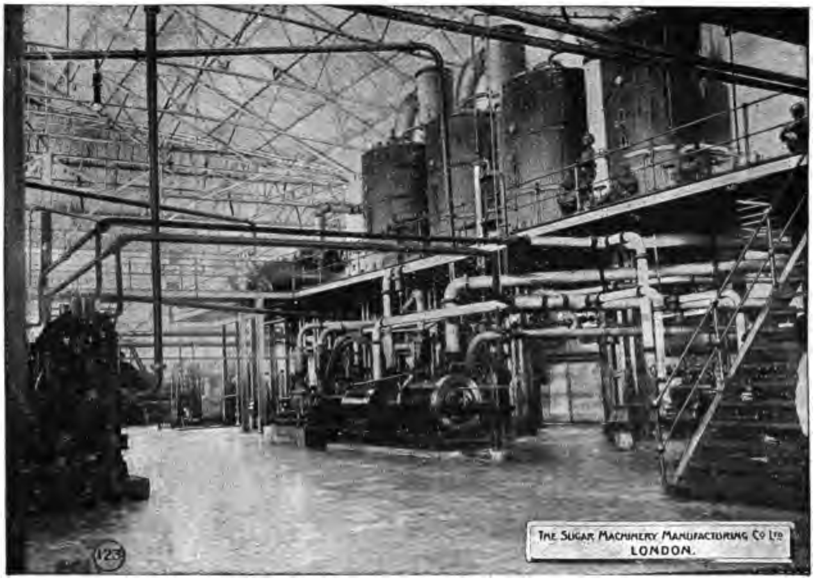
THE

SUGAR MACHINERY MANUFACTURING Coy. Ltd.

Telegraphic Address:
"PROOFSTICK," LONDON.

Codes used:
Engineering, Western Union,
A B C, Commercial, A1.

Head Offices: 76, ELSHAM ROAD,
LONDON, W.



EVAPORATOR SECTION OF A FACTORY RECENTLY CONSTRUCTED BY US.

We are DESIGNERS and MANUFACTURERS of MODERN CANE SUGAR MACHINERY and HOLD MANY PATENTED SPECIALITIES.

COMPLETE CANE SUGAR FACTORIES.

EXISTING FACTORIES REMODELLED.

Managing Director: ROBERT MITCHELL, M.I.Mech.E.

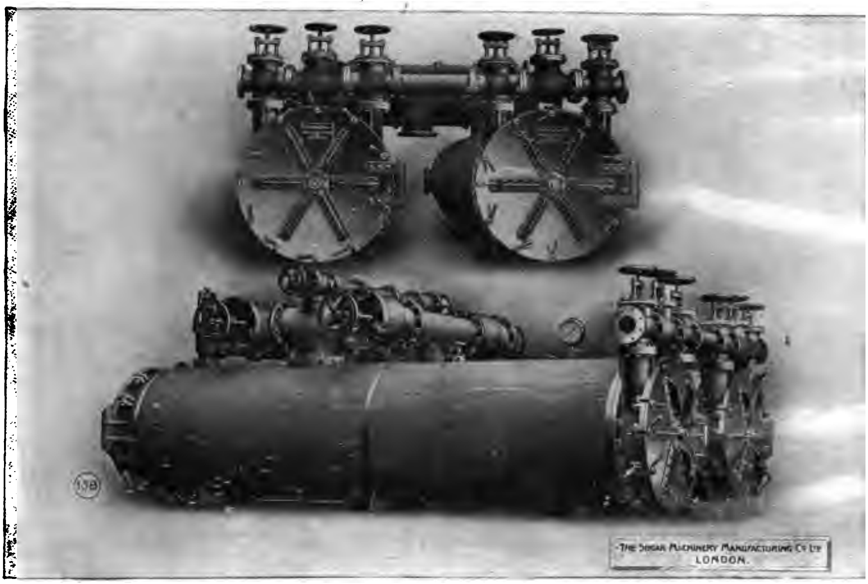
from
M. A. Lockwood, Chief Engineer [redacted]

THE
SUGAR MACHINERY
MANUFACTURING Coy. Ltd.

Telegraphic Address:
"PROOFSTICK," LONDON.

Codes used:
Engineering, Western Union,
A B C, Commercial, A1.

Head Offices: 76, ELSHAM ROAD,
LONDON, W.



HORIZONTAL QUICK-SPEED JUICE HEATERS.

We make a Speciality of

WHITE SUGAR FACTORIES
BY THE
CARBONATATION
OR
SULPHITATION
PROCESSES.

GIFT OF
Mrs. Burton F. Dinsmore

SIGILLVM · VNIVERSITATIS · CALIFORNIENSIS
FIAT LVX
MDCCCLXVIII

EX LIBRIS

NA Lockwood
Ogden Utah

N.A. LOCKWOOD
OWNER
OGDEN UTAH
1-15-1914

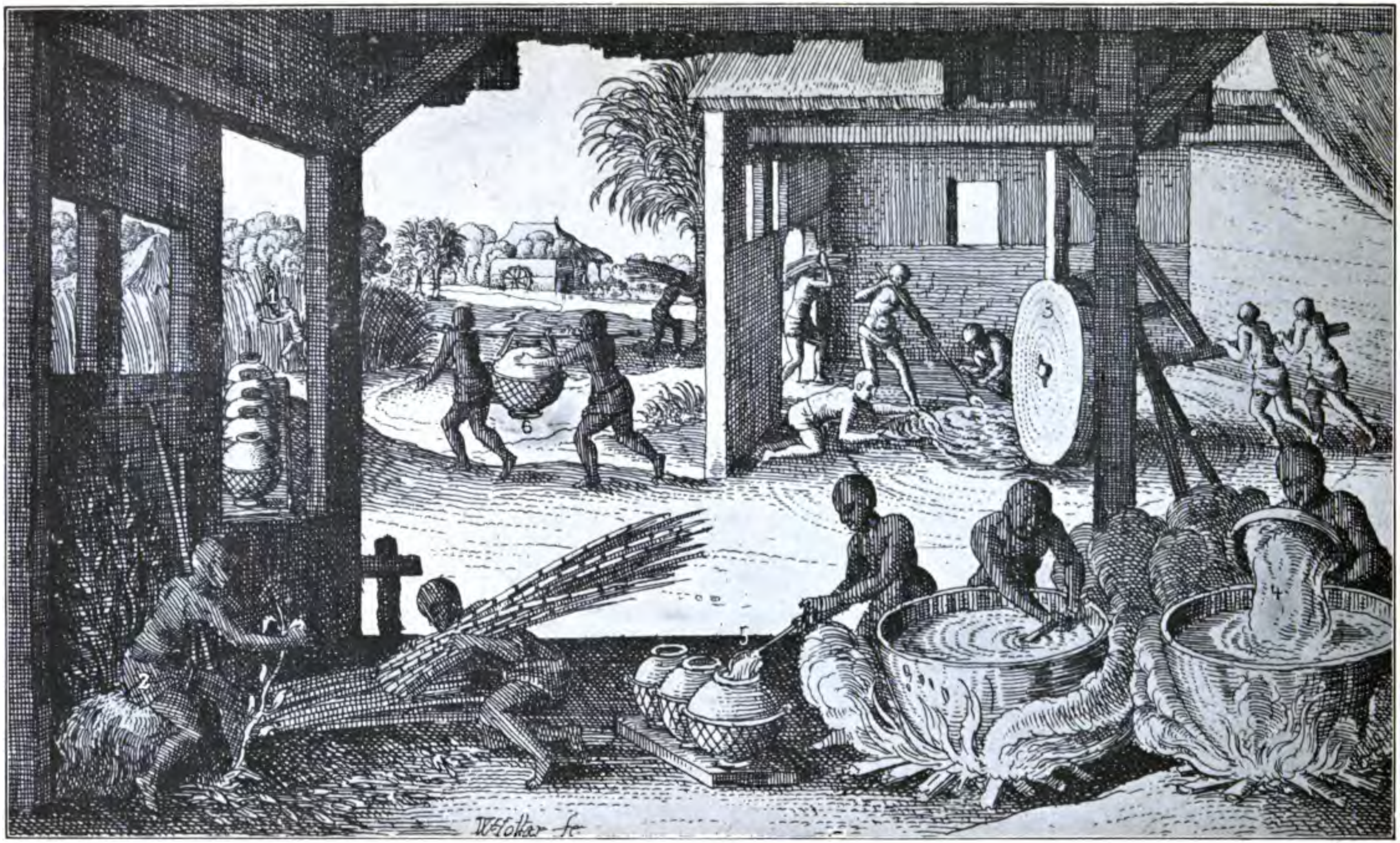


PLATE I.—Sugar Mills in Brazil.

In the foreground is a mill driven by hand; in the far background is one driven by water power. The original engraving was in the Atlas of Stolk, No. 1710, published, on the occasion of the Capture of Olinda in 1630, by Nicolaas Johannes Visscher. The Scene illustrates the period when the Dutch owned Brazil. *1.* Cutting the sugar cane. *2.* Stripping the leaves. *3.* Crushing in the mills and gathering the juice in the vats. *4.* Clarifying the juice in the pans. *5.* Transferring the juice from the pans to big pots. *6.* Juice in the pots being conveyed to a spot where it was set to harden, after which it was pressed into boxes and shipped.

EVAPORATION

IN THE CANE AND THE BEET SUGAR FACTORY.

A THEORETICAL AND PRACTICAL TREATISE.

BY

EDWARD KOPPESCHAAR,

FORMERLY TECHNICAL MANAGER OF THE VIERVERLATEN SUGAR FACTORY,
HOLLAND.

LONDON:
NORMAN RODGER,
ST. DUNSTAN'S HILL, E.C.

1914.

To the Memory of my beloved Father.

TP 377
K6

PREFACE.

After the appearance of so many excellent treatises on this subject by **Jelínek**, **Horsin-Déon** Sr., **Foster**, **Abraham**, **Claassen**, **Greiner**, **Brunings**, **Bolk**, **Saillard** and **Hausbrand**, the issue of yet another may seem superfluous. Partly, however, because in these existing books the special requirements of the cane sugar industry are somewhat overlooked, and partly because an attempt at discussing the subject in a simpler manner than has hitherto been attempted seemed desirable, the author has been encouraged to compile this volume. He has done so in the hope that he has brought the significance and value of the principles of evaporation within the easy reach of a wider circle of those interested.

Although great care has been bestowed upon the revision of the manuscript by Mr. **Norman Rodger** and Mr. **James P. Ogilvie**, F.C.S., as well as by the author himself, yet where so many figures and formulae occur the entire avoidance of errors is a matter of much difficulty. Consequently, for any criticisms involving amendments or simplifications to appear in future editions the author would be grateful. A series of coefficients of heat transmission relating to a complete Kestner quadruple system, for example, would be specially welcomed.

The author has also to acknowledge his indebtedness to a number of parties for permission to reproduce ten of the illustrations found in this volume; to Mr. **Noël Deerr** for Figs. 19 and 20 which are taken from his work "Cane Sugar"; to Mr. **Martinus Nijhoff** for the loan of blocks to illustrate Plates I to IV, these being derived from **Reesse**'s work, "De Suikerhandel van Amsterdam"; to the **Harvey Engineering** Co., **Ltd.**, of Glasgow, for the photograph of a triple effect shown as Plate V; to the **Nederlandsche Fabriek van Werktuigen en Spoorwegmateriaal**, of Amsterdam, for the loan of the blocks for Plates VII and IX; and lastly to the **Breitfeld-Danek Engineering** Co., of Prague, for the means to reproduce Plate VIII.

ED. KOPPESCHAAR.

The Hague,
October, 1913.

M510975

CONTENTS.

CHAPTER I.

INTRODUCTION.

PAGE

The Necessity for Evaporation and its Application in Cane and Beet Sugar Manufacture 1

CHAPTER II.

THE STUDY OF STEAM. ITS APPLICATION TO EVAPORATION IN GENERAL, AND TO MULTIPLE EFFECT EVAPORATION IN PARTICULAR.

Properties of Water, Steam, and Heat. Temperature Scales. Pressure Units. Evaporation and Boiling. Steam and its Properties. Heat and its Application. Sensible Heat. Total Heat. Transformation 2

CHAPTER III.

HISTORICAL DEVELOPMENT OF EVAPORATION IN THE CANE AND THE BEET SUGAR FACTORY, INCLUDING THE INTRODUCTION OF MULTIPLE EVAPORATION.

Java Native Sugar. Invention of the Vacuum Pan. Invention of Multiple Evaporation. Historical Review of the Use of Coal for Evaporation. Historical Development down to the Present Day . 18

CHAPTER IV.

COMPARATIVE STUDY OF EVAPORATION IN THE CANE AND THE BEET SUGAR FACTORY.

PAGE

Primitive Methods in Java, and in Europe. Quantity of Water to be Evaporated, in Beet and in Cane Sugar Factories. Method of Extraction. Method of Liming and Manufacture. Content of Cellulose. Incondensible Gases and their Elimination. Quantity of Exhaust Steam Available 31

CHAPTER V.

MULTIPLE EFFECT EVAPORATING APPARATUS.

Economy. Capacity. General Caloric Balance of Heat. Designing of Evaporating Apparatus. Standard Coefficients of Transmission. Standard Differences of Temperature. Design of 1200 Metric Tons' Plant, Beet and Cane 52

CHAPTER VI.

FUNDAMENTAL PARTS AND ACCESSORIES OF EVAPORATING APPARATUS.

Material. Measurements. Discharge of Condensed Water. Horizontal Pans *versus* Vertical. Incrustations. Heaters of Juice, and the Conditions which control their Efficiency. Transmission in Heaters. Central Condenser, Caloric Values. Air Pumps. Isolation 65

CHAPTER VII.

THE CONTROL OF THE EVAPORATING APPARATUS.

Necessity of Control. Extent of Control. Quantity of Water which is Evaporated. Chemical Control. Actual Tests, and Economy obtained. Ammonia Tubes and their Influence. Measurements of Ammonia Tubes. Influence of Incrustations on Use of Steam. Quantity of Scale. Cleaning of Tubes. Abnormal Mutual Relations of Heating Surfaces Transmission in Horizontal Evaporating Pans 79

CHAPTER VIII.

Special Designs.

PAGE

Different Types and Names of Designers. Test of Kestner Pre-evaporator. Transmission in Kestner. Utilization of Vapour from Vacuum Pan. Thermo-compressor and its Theory . . 93

CHAPTER IX.

Evaporation and Crystallization in Vacuum Pans.

Historical. Difference of Requirement compared with Evaporating Pans. Water evaporated in Vacuum Pan. Graining. Coefficient of Supersaturation. Sizes of Pans. Heating Surface of Pans. Transmission of Heat. Capacity of Pans. Requirements of Pans. Improvements in Designs . . , ... 99

TABLES.

Tables of Steam 112
Metric System 114
Thermometer Scales 115

LIST OF PLATES.

I. Sugar Mills in Brazil . . . . . . Frontispiece.

To face page

II. A Sugar Factory in Brazil 18

III. "De Granaatappel" Sugar Refinery . . . 22

IV. Interior of "De Granaatappel" Sugar Refinery . 26

V. Harvey's Patent Triple Effect Evaporator . . 52

VI. Diagram of Triple Effect Evaporator . . . 70

VII. Type of Low Vacuum Pan with Coils . . . 99

VIII. Freitag Vacuum Pan 106

IX. Type of Low Vacuum Pan with Coils and Wood Casing 110

EVAPORATION IN THE CANE AND THE BEET SUGAR FACTORY.

A Theoretical and Practical Treatise.

CHAPTER I.

INTRODUCTION.

The Necessity for Evaporation and its Application in Cane and Beet Sugar Manufacture.

In factories devoted to the production of cane or beet sugar, the sugar contained either in the cane stalk or in the beetroot has to be extracted by some method or other in order ultimately to obtain a finished product in marketable form.

Whether these methods of extraction are effected by means of roller-mills, diffusion batteries, or a combination of the two, the sugar is primarily obtained in the form of a solution, containing besides sugar a large part of the non-sugars originally present in the raw material. In order then to yield its sugar content in solid form, it has first of all to be freed as much as possible from these solid non-sugars present in the liquid.

This resulting pure sugar solution must accordingly be considerably reduced in volume in order to render crystallization possible. The crystallization proper is necessarily an intermittent process, and needs the close supervision of a trained attendant, the reduction in volume being divided into two stages.

The first stage is continuous, and to a certain extent even automatic, needing very little supervision; it serves only to reduce the volume of the sugar solution to a certain limit (which limit for each industry will be discussed later on).

The second stage begins where the first ends, is not continuous, and is regulated from moment to moment by the trained hand of an expert. It is therefore not automatic, but is continually kept in hand and controlled until the contents of the pan are ready to be passed into the crystallizer.

In both the cane and the beet industries, the study of these processes and the factors that influence their economical application has a very great effect on the financial result, especially in regard to the use of fuel.

While an attempt will be made to lay down in the following chapters the fundamental laws regarding the subject, it is also hoped that the details, methods of control, and the various relative calculations, etc., will not only be of use to men called upon to design evaporating plant, but also to owners, superintendents, engineers, or chemists who desire to know the actual capacity of their apparatus, check their results as to economy, or perchance improve or enlarge an existing installation.

In describing or discussing a phase of an industry, which like everything else has been developed and improved through a gradual process of evolution, it is not pretended that any entirely new points of view can be offered in these pages. To the original pioneers who brought light on the theory of evaporation, such as HUGO JELINEK and HORSIN-DÉON, senr., later years have added others who have done their share in making these theories better understood, especially because they have tested the data by actual practice in the factory. Thus to CLAASSEN and BRUNINGS we owe much; and the writer has had occasion to make use of the results of their work in this treatise. At the same time he has as far as possible also made use of his own experience and practical investigations.

Although of all the stages of manufacture Evaporation differs least in the two sister industries, it will be worth while to point out what differences do exist in cane and beet sugar evaporation plants, due to the different properties of cane and beet juice and the different methods of manufacture.

CHAPTER II.

THE STUDY OF STEAM.

Its Application to Evaporation in general, and to Multiple Effect Evaporation in particular.

To reduce a sugar solution in volume implies that part of the *water*, which holds the sugar in solution, is transformed into *steam*. This steam is drawn off by means of pumps, and condensed; and as a result the sugar solution becomes more and more concentrated. This withdrawal of water, changed into another body, namely, *steam*, is effected by the aid of *heat*.

The properties of *water*, *steam*, and *heat* must first be briefly discussed.

Water, the combination of one part by weight of hydrogen with eight parts of oxygen, we know in either the solid, liquid, or gaseous form. Its change from one state to another is effected by the application of heat. Ice changes into water, and water into steam, by absorbing heat from a source of heat. So, *per contra*, if steam changes into water, *i.e.*, condenses, or water turns into ice, heat is set free and becomes available for use. Of course, the chemical composition of water, while these changes occur, remains the same.

The conditions, which determine whether water be solid, liquid, or gaseous, are *temperature* and *pressure*.

Temperature we measure by the aid of the thermometer, which registers the expansion of a column of mercury or alcohol. The three different scales of thermometers in general use may be compared as follows:—

	Centigrade.	Réaumur.	Fahrenheit.
Freezing point of water.. ..	0° ..	0° ..	+ 32°
Boiling point of water	100° ..	80° ..	+ 212°

x° Centigrade $= 32^\circ + \frac{9}{5}\, x^\circ$ Fahrenheit $= \frac{4}{5}\, x^\circ$ Réaumur.

x° Réaumur $= 32^\circ + \frac{9}{4}\, x^\circ$ Fahrenheit $= \frac{5}{4}\, x^\circ$ Centigrade.

x° Fahrenheit $= \frac{5}{9}\,(x^\circ - 32^\circ)$ Centigrade $= \frac{4}{9}\,(x^\circ - 32^\circ)$ Réaumur.

Pressure, whether positive, or negative (a vacuum), in order that it may be measured is compared with a unit. Originally this unit was compared with and expressed as a column of mercury having a diameter of 1 sq. cm., and balancing against the pressure of the atmosphere. The weight of this mercury column of a specific gravity of 13·596 is $760 \times 100 \times 13{\cdot}596 = 1{\cdot}0333$ kg. at the average atmospheric pressure. As the corresponding volume of water balancing this weight is 1033 cub. cm., the height of such a column of 1 sq. cm. will be 1033 cm. = 10·33 metres. Thus we find :—

> 1·033 kg. pressure per sq. cm. of surface is equal to 10·33 metres of a column of water 1 sq. cm. in diam., or 760 mm. of a column of mercury of 1 sq. cm. in diam.

This pressure is the unit, and is termed an "atmosphere."

The conversion of water from the liquid to the gaseous state and *vice versa* is being continuously carried out in sugar manufacture during the processes of *evaporation* and *condensation* respectively.

Evaporation.—In general water will, at any temperature above freezing point, change into vapour if in contact with the air, and this need not necessarily be apparent. In the case of a wet cloth gradually drying when exposed to a breeze, the cloth becomes dry though the vapour is not visible. Similarly evaporation takes place on the surface of the ocean, but in this case it is made evident by the clouds that originate therefrom.

This evaporation is limited to the surface of the fluid in question. It will take place at any temperature between 0° and 100° C. The more heat reaches the water, the quicker evaporation will take place. The more readily the vapour is absorbed by the atmosphere, the more quickly the process goes on.

For any liquid this surface evaporation tends to increase when heat is applied to it, until vapour bubbles are developed within the liquid as well. These bubbles rise to the surface and pass into the atmosphere. The fluid is then said to *boil*, and the temperature at which this takes place is called the *boiling point*.

The bubbles of vapour have to overcome the pressure resting on them in order to be able to rise; the smaller this resistance, the easier and the quicker they will rise to the surface.

Thus it will be readily understood that the boiling point will be reached sooner, if the water is heated on the top of a high mountain, while at the bottom of a mine the boiling point will be less readily attained. In the first case the atmospheric pressure is less, hence the temperature of the boiling water is lower, while in the second case the pressure is greater, and the boiling point is correspondingly raised.

If we artificially reduce the pressure acting on a fluid, we similarly effect a lowering of the boiling point. On the other hand, if we prevent the vapour produced from finding an outlet, and thus increase the pressure, the boiling point will be correspondingly raised. The influence of pressure on the boiling point of water is shown in the following tables :—

Pressure of Mercury in		Equal to an absolute Vacuum of		Water under this pressure boils at the temperature of
Mm.	Inches.	Mm.	Inches.	
10	$\frac{3}{8}$	750	$29\frac{1}{2}$	11·3° C.
100	$3\frac{15}{16}$	660	26	51·7° C.
200	$7\frac{7}{8}$	560	$22\frac{1}{16}$	66·5° C.
300	$11\frac{13}{16}$	460	$18\frac{1}{8}$	75·9° C.
400	$15\frac{3}{4}$	360	$14\frac{3}{16}$	83·0° C.
500	$19\frac{11}{16}$	260	$10\frac{1}{4}$	88·7° C.
600	$23\frac{5}{8}$	160	$6\frac{5}{16}$	93·5° C.
700	$27\frac{9}{16}$	60	$2\frac{3}{8}$	97·7° C.
760	$29\frac{15}{16}$	—	—	100·0° C.
860	$33\frac{7}{8}$	—	—	103·5° C.
960	$37\frac{13}{16}$	—	—	106·6° C.
1060	$41\frac{3}{4}$	—	—	109·6° C.
1160	$45\frac{11}{16}$	—	—	112·2° C.
1260	$49\frac{5}{8}$	—	—	114·7° C.

Again, the boiling point does not depend only on temperature and pressure, but also on the nature of a liquid, for different fluids boil at different temperatures. Thus the boiling points at sea level for the following liquids are as follows :—

Methyl alcohol	66° C.	Turpentine	157° C.
Alcohol	78°	Sulphuric Acid	325°
Benzene	80°	Mercury	350°
Water	100°	Linseed Oil	387°

If solids are dissolved in the liquid, the boiling point will be higher, the increase depending on the nature and amount of the solids.

In CLAASSEN's tables it is seen that the more sugar an aqueous solution holds the higher is the boiling point; and that, moreover, it will be still higher the more non-sugars there are contained in it.

Thus:—

A 50 per cent. sugar solution boils at			.... ..	101·8° C.
An 80	,,	,,	.. ....	109·4°
A 94	,,	,,	.... ..	130·5°

When the sugar solution consists partly of sugar and partly of non-sugar, this influence may be seen thus:—

The Solution containing	Boiling point when the Purity of the Solution is 100°	93°	83°	73°	62°
50 per cent. solids..	101·8 ..	102· ..	102·25 ..	102·7 ..	103·15
80 per cent. solids..	109·4 ..	110· ..	111·4 ..	112·2 ..	113·6

On comparing the boiling point of a sugar solution with that of water, a difference in the pressure will be noticed.

In the case of water, the boiling point has its corresponding pressure. In sugar solutions this pressure is lower than the pressure of water boiling at the same temperature. Thus:—

> Thick-juice containing about 60 per cent. of sugar boils at 103·3° C. at a pressure of 1 atmosphere (14·7 lbs.), while water boils at 103·3° C. at a pressure of 1·12 atmosphere.
>
> Syrup in the vacuum pan containing about 80 per cent. of sugar boils at 110° C. at a pressure of 1 atmosphere (14·7 lbs.), while water boils at 110° C. at a pressure of 1·42 atmosphere.
>
> Syrup containing 90 per cent. of sugar boils at 120° C. at a pressure of 1 atmosphere (14·7 lbs.), while water boils at 120° C. at a pressure of 1·96 atmosphere.

Steam and its Properties.—The property of foremost interest possessed by steam has been mentioned already. If steam be produced in a closed vessel, the pressure of that steam will correspond to the temperature of the boiling water. When this fixed point is reached, no further vaporization will take place unless the temperature is increased, in which case the pressure will be increased proportionately. When steam has reached this fixed point, it is termed *saturated;* and it contains at that pressure, corresponding to a fixed temperature of the boiling water, a certain quantity of water in the form of vapour.

Increasing the pressure means condensing part of the steam until the "saturation point," which belongs to the new pressure and temperature, is reached.

Reducing the pressure means more violent ebullition and more steam produced, which will restore the saturated condition again. If saturated steam is enclosed and heated, it contrives to absorb still more heat, when the temperature rises and is no longer in relation to its pressure. The properties of this *superheated* steam are similar to those of gases.

The main property, which constitutes the chief economic value of *superheated* steam, is that it will condense more slowly than will *saturated* steam.

If for instance a factory superheats its steam by making use of the heat otherwise lost in the flue gases, and by so doing arranges that practically no loss through condensation in the steam tubes takes place, the economy is apparent.*

When, however, we use superheated steam for heating purposes, it must first change again into saturated steam before it will condense. Actual tests have confirmed this, and proved that it yields its heat much more slowly than does saturated steam. It is this property which has so far prevented its application for evaporation purposes.

Heat and its Application. In British India and Java the natives still use the most ancient methods of reducing their sugar solutions to either syrup or to crystals. The juice obtained from the flowering stalk of the palm tree (especially the *Arenga saccharifera*), or from cane stalks, by pressing them between primitive rollers, is concentrated in open pans exposed to the heat of a direct fire. In the early days of the beet sugar industry, this method of direct heating by fire was used, until, for reasons to be mentioned further on, the procedure was changed and steam was substituted.

In regard to direct fire and steam evaporation the following points should be noted:—

---

* Besides these gains, superheated steam makes it possible to attain a greater pressure and thereby an increased source of power in our steam engines. To produce *saturated* steam of 1·4 atmosphere (absolute) pressure, 643 calories are needed. If we superheat this steam and add 26·6 calories to it, or 4·13 per cent., we obtain a pressure of 14 atmospheres (absolute), or 10 times as much.

1. *Sufficient heat must be yielded whether originating from the direct heat of a fire or from steam.*
2. *This heat must reach the fluid by passing through a partition.*
3. *The sugar solution must absorb the heat.*
4. *The absorbed heat must effect evaporation.*

In studying these processes, and recording the results, use is made of a heat unit. For Continental Europe and the United States, the *calorie* is accepted as the heat unit. A calorie represents the heat required to make 1 kg. of water at atmospheric pressure rise through 1 degree Centigrade.

In Great Britain and the English Colonies the heat unit employed is the *British Thermal Unit.* (B.T.U.), which is the quantity of heat necessary to raise 1 lb. of water at sea level atmospheric pressure through 1 degree Fahrenheit.

1 calorie = heat required to raise 1 kg. water through 1° C.
1 „ = „ „ 2·2 lbs. water through 1·8° F.
1 „ = 3·968 B.T.U.

$$1\ \text{B.T.U.} = \frac{1}{2{\cdot}2 \times 1{\cdot}8} = \frac{1}{3{\cdot}96} = 0{\cdot}25 \text{ of a calorie.}$$

For other substances than water, the amount of heat required to raise 1 kg. of substance through 1° C. is not the same; it corresponds to the specific heat which has been accurately determined by experiment.

For instance, the specific heat of

Water .. .. = 1 | Cast-iron .. = 0·13
Ice .. .... = 0·90 | Brass .. .... = 0·094,

and with constant pressure—

Steam .. .. = 0·475 | Air.. .. .. .. = 0·2375.

Calorific tests* of sugar solutions have proved, as might have been expected, that at 15° C. they possess different specific heats :—

	Brix.	Specific Heat.
Thin-juice	12°	0·945
First body thick-juice	15°	0·923
Second „ „	20°	0·904
Third „ „	30°	0·833
Fourth „ „	62°	0·650

---

* By Dr. W. van Dam, *De Suikerindustrie*, 1903, 13.

Thus, to cause 1 kg. of thick-juice to rise through 1° C., the heat required is much less than in the case of 1 kg. of thin-juice.

Sensible Heat.—When water is heated, its rise in temperature can be readily perceived, until the boiling point is reached. The heat thus absorbed is called *sensible heat,* and is equivalent to the temperature.

Once the boiling point is approached, the heat supplied does not effect any further rise in temperature, but *boiling* commences; the heat causes the water molecules to overcome their cohesion, and a change of form, from water into steam, is the result. This heat absorbed in converting the liquid into a gas is called *latent heat.* The lower the boiling point, the more energy—the more calories—is needed to change the water into steam; as an instance, actual tests have proved that:

At 50° C.	571	calories are needed.
„ 60° C.	564	„ „ „
„ 70° C.	557	„ „ „
„ 80° C.	550	„ „ „
„ 90° C.	543	„ „ „
„ 100° C.	537	„ „ „
„ 120° C.	522	„ „ „

Clausius proposed a general formula which represented the heat needed to change 1 kg. of water of t° C. into vapour of t° C., viz.:—
$607 - 0{\cdot}708 \times t$ calories.

If the reverse takes place, that is, if 1 kg. of steam at t° C. be changed into 1 kg. of water at t° C., the same amount of heat will be set free and will become available.

Total Heat.—When we add the sensible heat to the latent heat, the sum will represent the heat required to change water at 0° C. to steam at t°. Some writers quite logically use the following formula:

$$t + 607 - 0{\cdot}708 \times t = 607 + 0{\cdot}3 \times t.$$ [*]

Regnault has measured the total heat, and expresses it by:

$$606{\cdot}5 + 0{\cdot}305 \times t,$$

which represents the heat necessary to change water at 0° into steam at t° C.

---

[*] $607 - 0{\cdot}708\, t + t = 607 + 0{\cdot}292\, t.$

Thus the latent heat required to produce the transformation of water at 100° into steam at 100° will be:

$$607 - (0{\cdot}708 \times 100) = 536{\cdot}2 \text{ calories,}$$

which amount will be available, when 1 kg. of steam of 100° is changed into water of 100°.

The total heat needed to change water at 0° into steam at 100° will be:

$$606{\cdot}5 + (0{\cdot}305 \times 100) = 637 \text{ calories.}$$

If this water had an initial temperature of 80°, these 80 calories of latent heat must be deducted:

$$637 - 80 = 557 \text{ calories.}$$

In the case of steam yielding its heat when being condensed, the latent heat will always be set free. If the condensation water also yields some of its sensible heat, this can be added to it. Such will be the case in heaters, where the heated juice is quickly replaced by colder juice.

Thus, if steam at 112° be condensed, and the condensed liquid runs off at 100°, the heat yielded will be:

$$607 - (0{\cdot}708 \times 112) + (112 - 100) = 540 \text{ calories.}$$

In modern cane and beet factories, direct heating by means of an open fire no longer plays any rôle except in the boiler house. For heating purposes in the factory, the steam is either injected into the liquid or its heat is applied through the medium of double bottoms, coils, tubes, stacks of tubes, or drums containing a series of tubes joined up by two end-plates.

The latter, having relation to our subject, we may divide into:

(*a*) *Heaters*, where a rise in temperature only is the desired result;

(*b*) *Evaporation apparatus*, where concentration is aimed at;

(*c*) *Vacuum pans*, where concentration and crystallization are desired;

(*d*) *Pauly pans* and *Kestner evaporators*, where concentration is combined with the production of high pressure steam.

In all these cases, the heat yielded by steam must be taken as the latent heat, $607 - 0{\cdot}708 \times t$.

It is true that in some instances the condensed liquid will yield some sensible heat as well, the exact amount of which we can only know when we measure the temperature of the condensed water,* but which, owing to varying amounts of incrustation, is never the same. Heat will be yielded up if the steam meets a surface having a lower temperature; and the greater this difference, the more readily the steam will condense. As gases and water are bad conductors of heat, both will, if not drawn off, form a cushion and gradually prevent condensation. Thus, the second condition for yielding heat by steam is that the condensed water shall be drawn off completely and quickly, and the air, carbonic acid gas, and ammonia be likewise led away.

The heat yielded must reach the fluid by passing through a wall. Different metals will conduct heat in varying degrees of rapidity. The capacity to conduct heat has been ascertained for solids as well as for liquids and gases. A unit by which this capacity is compared is the heat conducted per minute through a cube of the metal, whose surfaces measure 1 sq. centimetre, the difference of temperature between the two opposite surfaces being 1° C. If this quantity of heat conducted be 1 calorie, the conductivity = 1.

By empirical tests, the following relative conductivities, taking iron as 100, have been found.

Silver	830	Tin	120	Bismuth	1·5
Copper	610	Iron	100	Water	0·9
Brass	200	Lead	70	Air	0·033
Zinc	160	Platinum	50	Lime Incrustations	10·0

Transmission.—The heat which is conducted through the tubes or coils in evaporating apparatus and vacuum pans is *transmitted* through the metal. For the purpose of calculation we express the quantity of heat transmitted from a warmer to a colder area of surface per minute, and 1° C. by the *coefficient of transmission of heat.* This factor, if known, is a measure for all the processes going on that together constitute heating or evaporation; which conditions we will recapitulate later.

---

* At the Vierverlaten sugar factory the author has repeatedly measured the temperature of the condensed water which flowed into an open tank from the raw-juice heaters. These heaters were fed by juice-vapour from the first body, at about 104° C. The temperature of the condensed water, however, was about 64° C. 1 kg. of juice-vapour yielded:—

$$607 - (0{\cdot}708 \times 104) + (104 - 64) = 574 \text{ calories,}$$

instead of:—

$$607 - (0{\cdot}708 \times 104) = 534 \text{ calories,}$$

which makes a difference of about 7 per cent.

The sugar solution must absorb this heat. The specific heat for solutions of different densities varies; thus, 1 kg. of thick-juice will absorb less heat in passing through 1° C. than will 1 kg. of thin-juice. Heat will be absorbed the better, (1) the greater the difference of temperature, since absorbing heat is nothing else but transferring heat from a warmer to a colder medium; and, (2) the quicker the heated molecules are replaced by colder ones.

To attain the first condition, *i.e,* that the temperature of ebullition be lower than the temperature of the steam used, resort is made to an air-pump to reduce the pressure, and consequently the boiling point.

The second condition depends entirely on the viscosity of the solution. This viscosity may be measured by means of an Engler or Redwood viscometer. The time in seconds taken by 100 c.c. of the liquid to flow through an orifice of standard size is the basis of comparison.

Claassen has shown in the following table that the viscosity of sugar solutions increases with the concentration, but decreases with the temperature.

Sucrose in 100 parts of water by weight.	Rate of flow in seconds.
100	22
160	47
188	88
219	164
224	187
230	217
236	248
242	280
248	318
256	373
270	464

The influence of higher temperatures is demonstrated by the following data, a saturated sugar solution at 30° C. being examined at different temperatures:—

Temperature °C.	Rate of flow in seconds.
16	476
21	330
25	246
30	163
37	114
42	86
51	54
61	39
71	30

The increase of temperature, however, surpasses the increase of concentration in its effect on the viscosity.

Sucrose per cent. by weight.	Temperature °C.	Rate of flow in seconds.
66·7	17	180
67·3	22	161
69·6	35	110
73·2	55	63
74·6	63	55
76·4	71	51

The conclusion to be drawn from these figures is that in the first body of a multiple effect evaporator, the combined conditions of high temperature and low sugar concentration must favour the transmission; and that in the last body with low temperature and high concentration, the viscosity will be greatest.

In heaters a certain rise in temperature is aimed at, and the heat needed to effect this rise after transmission and absorption will depend upon the difference of temperature before and after heating, and upon the specific heat.

While for raw and thin-juices the specific heat required may be accepted as *1*, for thick-juice and syrup it is lower, being about 0·7.

In evaporators the heat needed to evaporate for instance 1 kg. of water of 90° into steam at 104° will be the total heat — the sensible heat:—

$$606{\cdot}5 + (0{\cdot}305 \times 104) - 90 = 548{\cdot}2 \text{ calories.}$$

When the latent heat needed to change water of 104° into steam at 104° is calculated and the sensible heat which the solution lacks, 104 — 90°, is added to it, the result will be practically the same:—

$$607 - (0{\cdot}708 \times 104) + (104 - 90) = 547{\cdot}4 \text{ calories.}$$

While both may be used, we will choose the total heat for use in our calculation, deducting the sensible heat which the solution already possesses.

Recapitulating, we find:—

Heat yielded by Steam

In Heaters,
Object: *Rise in Temperature.*
1 kg. yields $607 - 0{\cdot}708 \times t$.

In Double Bottoms, Coils, Tubes,
Object: *Evaporation.*
1 kg. yields $607 - 0{\cdot}708 \times t$.

Heat required by Liquid

In Heaters,
The Rise in Temperature
× Specific Heat.

In Evaporators and Vacuum Pans,
1 kg. of Water needs
$606{\cdot}5 + 0{\cdot}305 \times t_{\text{steam}} - t_{\text{solution}}$.

Kg. of Steam needed

In Heaters,

$$\frac{\text{Kg. of Juice} \times (t_{\text{out}} - t_{\text{in}}) \text{ Specific Heat.}}{607 - 0{\cdot}708 \times t_{\text{steam}}.}$$

In Double Bottoms, Coils, Tubes
of Evaporation Apparatus, and
Vacuum Pans,
Kg. of Water

$$\frac{606{\cdot}5 + 0{\cdot}305 \times t_{\text{steam}} - t_{\text{juice}}.}{607 - 0{\cdot}708 \times t_{\text{steam}}.}$$

The steam needed to evaporate 1 kg. of water will depend on the latent heat of this steam and on the boiling point of the water, combined with the sensible heat already present in this water. For general calculations we can safely assume that *1 kg. of steam evaporates 1 kg. of water*.

As the absorption of heat by a sugar solution does not take place without influencing, more or less, the sugar itself, the enumeration of the chemical changes that result, as demonstrated by various investigations, may be added to this chapter.

First, the main difference between beet and cane juices must be mentioned. The *glucose* (reducing sugars) in the cane goes to form part of the thin-juice, and contrasts with whatever small quantities may be found in the beet,* which are destroyed in the lime-mixers by the action of the lime.†

Therefore it is only as regards cane juices that the action of heat on glucose must be considered.

The action of heat on the *mineral solids* dissolved in the cane and beet juice is of another nature, but of equal importance in regard to the transmission of heat.

---

* 0·4–1·5 per cent. in sound cane; and 0·10–0·12 per cent. in sound beets.

† *International Sugar Journal*, March, 1912, p. 154.

The influence of high temperatures on sugar solutions has been studied by **Herzfeld**, and of late, by **Deerr**, **Hazewinkel**, **Duschsky**, **Zujew**, and **Loukianoff**. **Herzfeld** made his solutions slightly alkaline (0·01 — 0·05 per cent.) to neutralize the acid which is formed by boiling sugar solutions.

In one hour per 100 parts of solution he found the sucrose to be destroyed at the following rates:—

	SUCROSE IN THE SOLUTION.		
Temperature °C.	10 per cent.	30 per cent.	50 per cent.
80	0·0044	0·0047	0·0100
90	0·0079	0·0087	0·0196
100	0·0114	0·0127	0·0292
110	0·0163	0·0167	0·0388
120	0·0282	0·0577	0·1399
130	0·2055	0·2600	0·5900
140	0·5100	—	—

And the decomposition per hour per 100 parts of sucrose was:—

Temperature °C.	SUCROSE CONTENT OF THE SOLUTION.								
	10 per cent.	15 per cent.	20 per cent.	25 per cent.	30 per cent.	35 per cent.	40 per cent.	45 per cent.	50 per cent.
80....	0·0444	0·0373	0·0301	0·0229	0·0157	0·0168	0·0179	0·0190	0·0200
90....	0·0790	0·0667	0·0541	0·0418	0·0290	0·0317	0·0344	0·0371	0·0392
100....	0·1140	0·0961	0·0781	0·0602	0·0423	0·0466	0·0508	0·0551	0·0584
110....	0·1630	0·1362	0·1093	0·0825	0·0557	0·0612	0·0667	0·0721	0·0766
120....	0·2823	0·2582	0·2341	0·2098	0·1857	0·2063	0·2669	0·2474	0·2678
130....	2·0553	1·7582	0·4610	1·1638	0·8667	0·9451	1·0235	1·0119	1·1800
140....	5·1000								

Zujew[*] carried out experiments in the Charkow Technical Institute with beet thin-juice from sound roots. After heating in an autoclave for five minutes at 132° C., he failed to detect any formation of reducing sugars.

Temperature °C.	Time.	Reducing Sugars formed.
132	5 minutes	Absent.
132	10 ,,	0·003 per cent.
112	10 ,,	0·018 ,, ,,
120	10 ,,	0·015 ,, ,,
134	10 ,,	0·016 ,, ,,
144	10 ,,	0·020 ,, ,,

---

[*] *International Sugar Journal*, 1911, 46.

Duschsky* used alkaline solutions with the following result:—
The loss of sugar in 100 parts originally present was:—

Temperature °C.	SUCROSE CONTENT OF THE SOLUTION.					
	50 per cent.	55 per cent.	60 per cent.	65 per cent.	70 per cent.	75 per cent.
80	0·0260	0·0260	0·0230	0·0200	0·0170	0·0170
90	0·0260	0·0490	0·0350	0·0280	0·0170	0·0350
100	0·0510	0·0710	0·0350	0·0350	0·0350	0·0510
105	0·0752	0·0752	0·0878	0·0878	0·0752	0·0752
110	0·0878	0·1003	0·1003	0·1003	0·0878	0·1003
115	0·1504	0·1837	0·1337	0·1837	0·1837	0·1672
120	0·3009	0·3009	0·2508	0·2508	0·2257	0·2006
125	0·7021	0·6519	0·7021	0·6018	0·6018	0·7021
130	1·3039	1·2537	1·3039	1·2036	1·1033	1·0531
135	2·1063	1·9057	1·7051	1·6549	1·8556	1·7051

Noël Deerr† used a 78 per cent. solution of sucrose and heated it for 30 minutes at different temperatures. The polarization after this heating was:—

At 110° C.	78·0	At 125° C.	73·7
,, 115° C.	77·3	,, 130° C.	61·2
,, 120° C.	76·5	,, 135° C.	35·3

Loukianoff,‡ in a Russian factory, observed a decrease in the purity and an increase in the colour, using a pre-evaporator in which the temperature of the steam was 140° C.

	Brix.	Sugar.	Purity.	Alkalinity.	Colour per 100 parts of Sugar.
On entering ..	21·7 ..	20·25 ..	93·3 ..	0·0255 ..	34·13
On leaving ..	24·68 ..	22·78 ..	92·3 ..	0·0225 ..	41·63

Hazewinkel§ investigated the change in the glucose factor of juice between entering and leaving a Pauly evaporator. He found:—

Entering the Pauly..	8·88..	16·23..	10·38..	8·90..	9·48..	8·21..	11·40..	10·15
Leaving the Pauly ..	8·65..	16·03..	10·41..	9·03..	9·62..	8·06..	11·28..	10·29

From these experiments the conclusion may be drawn that loss of sucrose will occur (1) the higher the temperature, (2) the longer the solution is exposed to this temperature, and (3) the more concentrated the solution is.

---

* *International Sugar Journal*, 1911, 46. † *Ibid*, 1911, 341. ‡ *Ibid*, 1911, 628.
§ *Ibid*, 1911, 212.

With the introduction of evaporation under pressure, in Pauly and Kestner apparatus, the question of decomposition has become of special interest. Experiments undertaken to find out whether sugar is decomposed to any appreciable extent, prove that in the latter type none or hardly any decomposition can be shown, owing to the great rate at which evaporation proceeds. Later, when discussing these modern apparatus, we will elaborate the facts now briefly mentioned.

Glucose, or reducing sugars, is very easily decomposed even at lower temperatures. According to PRINSEN GEERLIGS,* the following takes place in regard to its destruction when heated:—

If a glucose solution be warmed below 70° with potash or soda, the alkaline reaction decreases, and the salts of two acids are formed, viz.: glucinic acid and saccharumic acid, the solution meanwhile becoming opaque. The first is easily decomposed into different acids, and saccharumic acid is also gradually decomposed. At higher temperatures, glucose is rapidly decomposed by alkaline solutions into black-coloured decomposition products.

In beet sugar factories this question is not of any great moment, but in cane sugar factories, especially those making white sugar, high temperatures should be avoided as long as the juice contains much free lime.

---

* "Cane Sugar and its Manufacture," p. 31.

CHAPTER III.

Historical Development of Evaporation in the Cane and the Beet Sugar Factory, including the Introduction of Multiple Evaporation.

Long before beet sugar was ever dreamt of, tropical countries produced sugar from cane or palm juices. To concentrate these, open pans in series, heated by open fire (see Plates I and II), so-called "Chinese batteries," were used. In Java, this method was followed in the larger factories up to the year 1840, while the method has been retained unchanged by the smaller native concerns up to the present date, in Java, British India, and other tropical countries. The author remembers the isolated *daroengans* in the primeval forest which covers the whole south coast of Java. The palm tree which is best suited to yield sugar is the *Arenga saccharifera,* which occurs here and there in these forests. The native sugar maker clears away the brush round them, builds a ladder and places a bamboo vessel underneath the stem of the flower tassel, which he has cut off previously. The juice thus collected is evaporated in iron pans, with the addition of a little milk-of-lime. The massecuite is filled into bamboo rings, and the slices of dark brown nicely flavoured palm sugar, *goela aren,* are brought to the market in bunches of 10 or 15, bundled up in palm leaves.

The same method is followed by the natives who plant cane. The primitive vertical wooden rollers, turned by the patient *sappie* or *karbouw,* are brought out to the cane field, and there in a small shanty the manufacturing process takes place. The product, *goela djawa,* does not come up to the standard of the sugar derived from the *arenga,* as regards flavour; and it cannot stand prolonged storage, as it is liable to be converted into a sticky syrupy mass. Still, the natives do not use anything else, and if the statistics covering its output were published, an astonishingly high figure would have to be added to the total of the world's production of cane sugar.

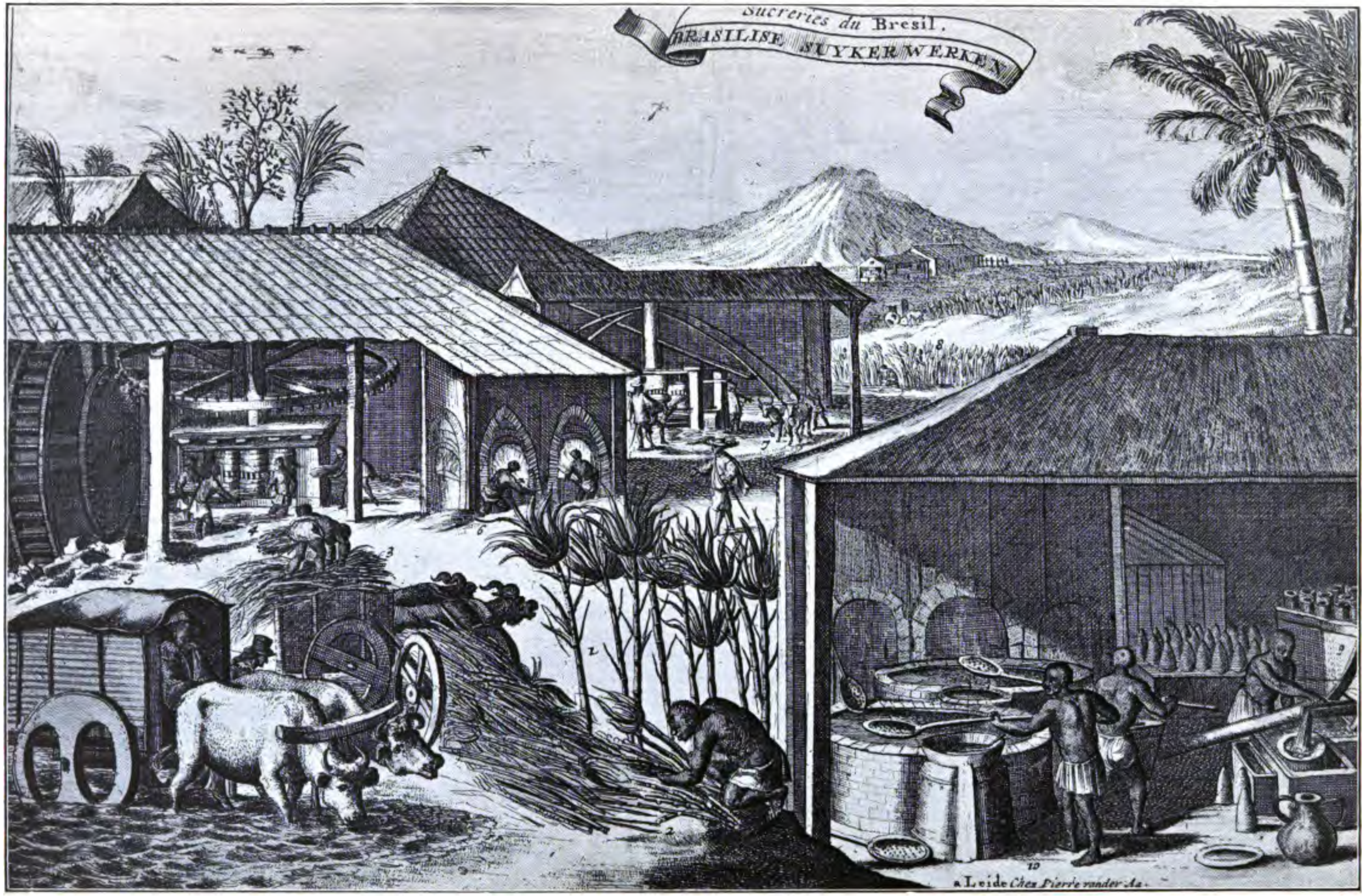


PLATE II.—A SUGAR FACTORY IN BRAZIL.

The mill on the left is after Barlaens, 1647. The print dates from the middle of the 17th century. *1.* Sugar cane. *2.* Cutting and selecting the cane. *3.* Transporting the cane in carts. *4.* Sugar mills. *5.* Waterwheel to drive the mills. *6.* Covered boilers and drying stoves. *7.* Mill worked by oxen. *8.* Sugar cane growing on the mountains. *9* and *10.* Purification of the juices by boiling and subsequent clarification.

That this method, using open fire, destroys sugar by caramelization, and is apt to produce dark-coloured products of decomposition from the glucose, especially if milk-of-lime be added, is clear enough as all the produce possesses a dark colour.

In the European refineries open fire was used as well (see Plates III and IV), and when the first beet sugar was manufactured, the same method was followed. The historical evolution of this part of sugar manufacturing is briefly the following :—

1. Open fire for evaporating purposes.
2. Substitution of steam-heating for open fire.
3. Introduction of the vacuum system of boiling.
4. Utilization of the latent heat of the juice-vapour.
5. Combining these last two into a series of pans, resulting in multiple effect evaporation.

Three men come prominently forward in this gradual development, and as far as we are able to draw our conclusions from the different sources, which often contradict one another, they should be named in the following order :—

Charles Edward Howard,
Degrand,
Robert Rillieux.

The first-named, who was born on May 18th, 1774, in England, and was a younger brother of the then Duke of Norfolk, certainly deserves prior mention, and to Professor Dr. E. O. von Lippmann* we owe our ability to give the following notes on his career. Howard seems to have received a good technical and chemical education. When but 26 years of age, he delivered before the Royal Society a paper on mercury fulminate, which explosive was discovered by him in 1800. After this he turned his attention to sugar refining; probably his marriage with the daughter of a refinery proprietor had much to do with this. In the years 1812 and 1813, Howard took out patents, which covered the following main points :—

---

* *Deutsche Zuckerindustrie*, 1912, 661.

(1) Device to clean the raw sugar crystals by means of water or steam (affining).

(2) Device to clarify the juices by chemical means, especially by alumina.

(3) A system of filters, the prototype of our own filter-presses, consisting of 65 frames, which were covered with cloth.

(4) The employment of a saturated sugar solution instead of using clay, to cover the sugar-loaves.

(5) A device to make sugar-loaves by pressing white sugar together.

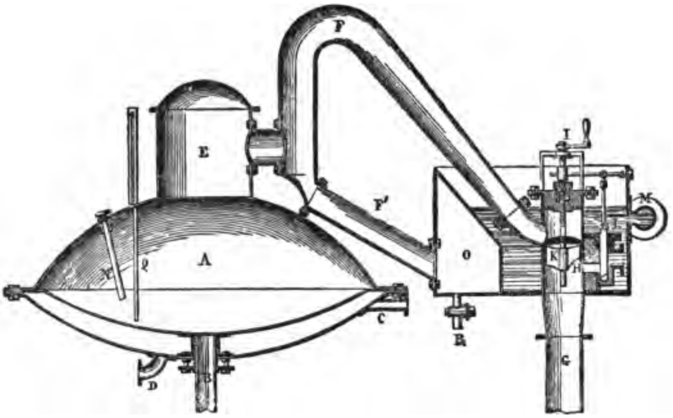


Fig. 1.

(6) The suppression of the open fired battery, met with everywhere in refineries, and the replacement of the many scattered fires by one central fire, *i.e.*, under the boiler. In other words, he recommended *the use of steam* in lieu of open fire, for all purposes, particularly *for evaporating and boiling.*

(7) A device to boil the juices into massecuite at a low temperature, to the benefit of the colour and yield of sugar. *This was to be attained by making use of vacuum, which was produced either by air-pumps or some other device.*

The new apparatus, the vacuum-pan (Fig. 1), thus created by Howard, consisted of two copper cones, surmounted by a dome. A double bottom received steam at 15 to 30 lbs. pressure; the condensed water was returned to the boiler; 60° C. was the temperature of the boiling juice—proof enough that his air-pump did good service. In order to examine the contents, **Howard** also constructed that important accessory, the proof-stick.

These pans were small, yielding 20 to 25 loaves. Their general design and their construction, presumably after many valuable experiments, were placed in competent hands; for **MacMurdo**, director of the engineering firm of **James Watt** and **Boulton**, in Manchester, was responsible for their manufacture.

As an immediate result, 5 per cent. more sugar was obtained, of a fine white quality, and 10 per cent. less syrup which, however, had a better colour and better taste.

Unlike many other men who made valuable discoveries, **Howard** reaped the financial reward of his work. A syndicate offered £40,000 for his patent, a large sum indeed for that time. But he refused it, and succeeded in obtaining a yearly royalty from the refineries which used his pans. This royalty amounted to £60,000 per annum in 1816. **Howard**, however, did not enjoy this income very long, as enfeebled in health, probably by overwork, he died suddenly on March 13th, 1816.

Up to the year 1827, when his patent expired, his pans remained practically the same; at that period forty of them existed in the London refineries, requiring in the aggregate pumps and engines of about 100 H.P.

In France, the first vacuum pan was installed by **Degrand** in 1824, at Marseilles. **Degrand** improved this apparatus in several ways. He introduced coils which made it possible to evaporate more quickly, and he also constructed sight-holes in his pans, which enabled the pan-boiler to see what was going on inside.

At about this same period we find mentioned the names of **Hallette** (see Fig. 2), **Pecqueur** and **Moulfarine**.* The latter two were constructors of sugar machinery in Paris. They used steam of greater pressure at a temperature of 150° C., and devised pans with tube bundles which could be turned round.

---

* **Horsin-Déon**, "Traité théorique et pratique de la Fabrication du Sucre," 1912 edition, p. 582. **Stohmann-Schander**, "Handbuch der Zuckerfabrikation," 1912 edition, p. 528.

The result of this improvement was that 100 kg. of water per hour per square metre of surface could be evaporated. In 1828, Roth constructed pans in Paris, using cold water in place of an air pump. To Degrand, however, we are indebted for important improvements, which paved the way for future inventors. His work attracted the attention of Derosne in Paris—unhappily enough for Degrand—as Derosne, director of the Maison Derosne and Cail, soon contrived to bind Degrand by contracts, thus acquiring for his firm not only the financial benefit, but also the fame from the inventive genius of Degrand.

In 1833 Degrand proved that great economy was to be had when the latent heat of the juice vapour was utilized to heat the juice before it entered the pan, a far greater concentration being reached in this way. In 1834 an apparatus called a *double effect,* devised by Degrand, but standing in the name of Derosne, was constructed. In 1837 double effects and triple effects are mentioned by Mornay, of which however no further description is given. In any case, for the idea of utilizing the latent heat of the juice vapour we are indebted to Degrand, and it is but just to restore all credit to him for his invention.

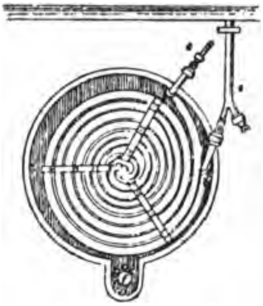


Fig. 2.
Hallette's Pan.

The third inventor, named Robert Rillieux, born in New Orleans in 1806, has no doubt proceeded on the results of those already named. Unquestionably, however, he has rendered incalculable services to the sugar industry by his inventions and improvements.

As Rillieux never contributed anything to technical publications

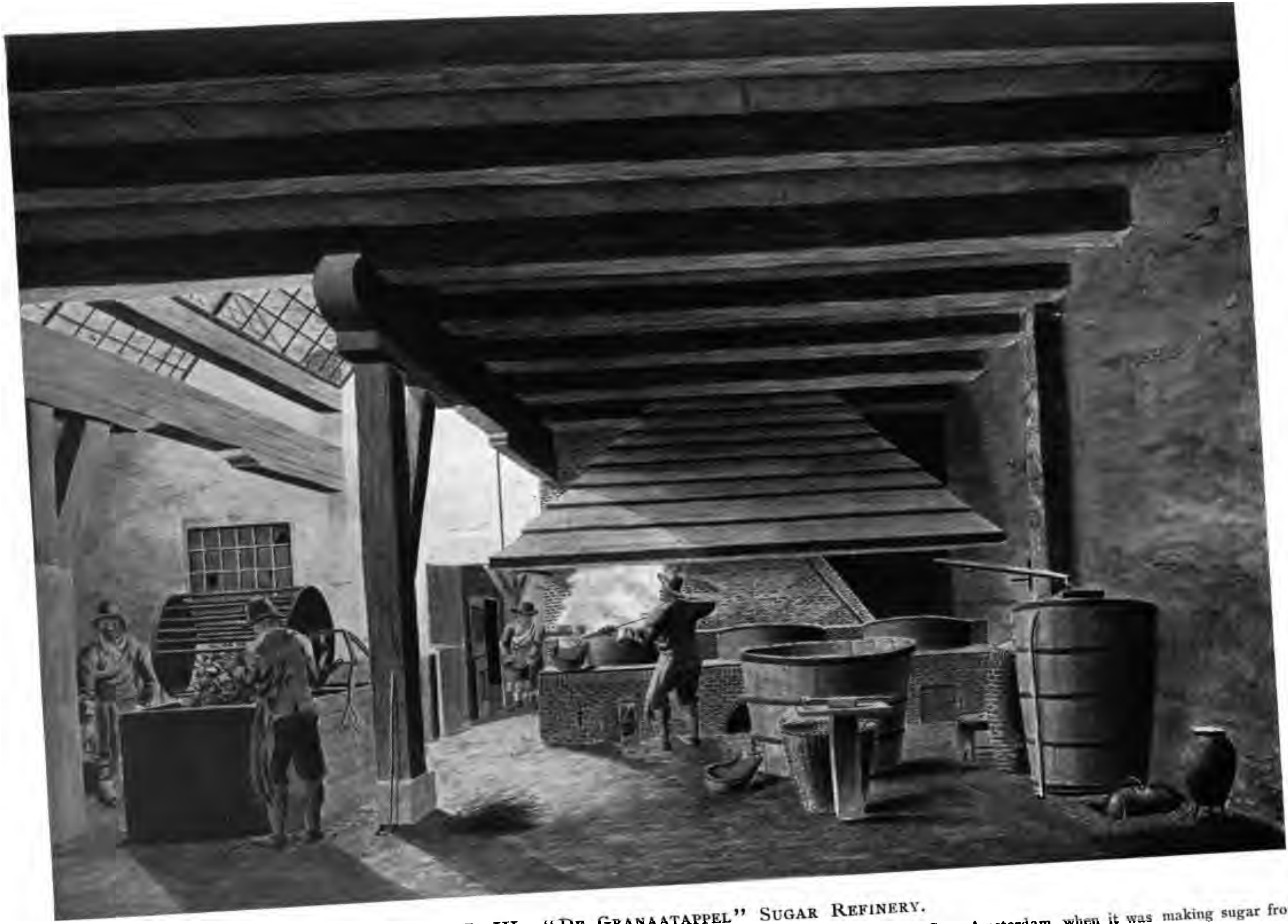


PLATE III.—"De Granaatappel" Sugar Refinery.

This peculiar old print represents the interior of the refinery which belonged to the firm of Wed. Scholten & Son, Amsterdam, when it was making sugar from beet in 1811. At the present day the refinery of Spakler & Tetterode stands on the same site.

by way of describing his inventions, the only sources of information left us are the specifications of the patents taken out by him, and the information given by Horsin-Déon, Junr., whose father was secretary to Rillieux, and by B. Dureau, who worked with his apparatus. Rillieux went to Paris in 1830 to study, and while there he communicated his ideas to Pecqueur. Meeting with no sympathy, he returned to the United States, and in 1843 took out a patent for his great invention.

The following information as to this evaporator is derived from Horsin-Déon's well-known book :—

" The Rillieux apparatus is based on the utilization of the latent heat generated by the cane or beet juice for concentrating this juice and bringing it to crystallization point. In this way a considerable amount of heat value is utilized, which is completely lost in open evaporators, or in pans under atmospheric pressure, like the Degrand apparatus.

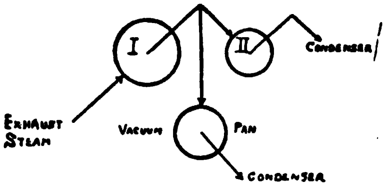


Fig. 3.

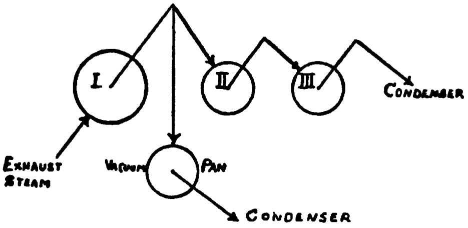


Fig. 4.

" The Rillieux apparatus is composed of three or four cylindrical pans made of sheet-iron, 10 × 3·5 ft., arranged parallel to each other and supported on cast-iron columns. Steam circulates from one pan to the other by means of valves and tubes. A dome surmounts each pan, which makes the evaporator look like a locomotive."

Rillieux made apparatus containing three and even four pans in series. From the description given, it appears that the first (Fig. 3) evaporated double effect and boiled* double effect, while the second (Fig. 4) evaporated triple effect and boiled double effect.

---

* That is, formed grain.

In this way, RILLIEUX utilized the large difference in temperature between the steam in the first pan and the boiling juice in the pan next to the condenser, for the difference between steam of 111° and juice boiling in a pan, where an air-pump aided by cold water circulation creates a vacuum of 600 mm. of mercury, will be about 50° C. This difference is far more than is actually needed if only one pan is installed. Suppose we evaporate juice in one pan connected with an air-pump and a condenser. The difference in temperature needed to cause boiling will be less for thin-juice than for thick-juice; since the more concentrated the juice, the greater the difference of temperature needed. Thus, the 50° C. may be divided into 3, 4, or 5 parts. *Each time the vapour produced causes boiling in the next pan, as many kg. of water are evaporated by 1 kg. of steam originally introduced into the first pan as the apparatus possesses vessels.*

RILLIEUX's invention was introduced into European factories under the following circumstances: BRAMI ANDROEA, formerly engineer of the Buckau Maschinenfabrik, was an assistant to RILLIEUX in America, and so was enabled to send plans to TISCHBEIN, director of the Buckau Maschinenfabrik. TISCHBEIN apparently did not understand that the last vessel in RILLIEUX's system was a vacuum pan. He constructed a triple pan apparatus which, however, evaporated in double effect, thus:

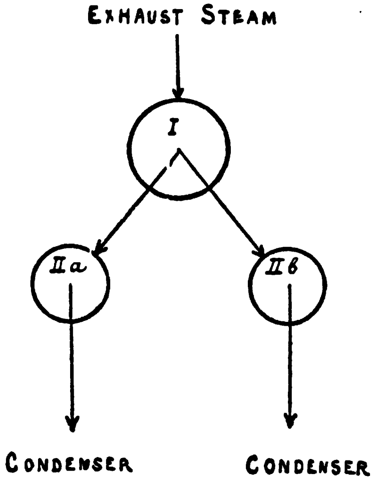


FIG. 5.

These plans also came into the hands of the Maison Cail, Paris, who constructed sets according to the same system, installing the first plant in the Coincy Sugar Factory at Douai, France.

The first engineer to construct apparatus according to RILLIEUX's real system was ROBERT, Director of the Seelowitz Sugar Factory. ROBERT changed the horizontal vessels into vertical ones,[*] and thus made the first real triple effect in Europe. (Fig. 6.)

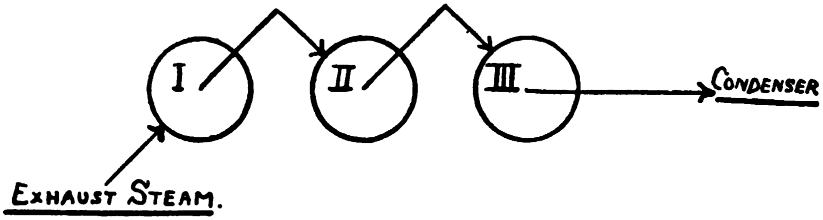


FIG. 6.

As to the economy attained, a record of the fuel used has been kept in the soda industry.

Since 1 kg. of coal evaporates as many kg. of water as the number of vessels, it is evident that a triple effect is more economical than a double, a quadruple effect better than a triple effect, etc. Still the division of the total temperature difference over several vessels cannot be continued indefinitely; and in the sugar industry a quintuple effect for all practical purposes forms the limit.

To concentrate 1 cub. metre of soda liquor from 10° to 48° Bé., equal to the evaporation of 864 kg. of water, the coal used was:

By direct fire	222	kg. of coal, or	25	kg. of coal per 100 kg. water
By steam in pans..	181	„ „	21	„ „ „
By simple effect vacuum ..	117	„ „	13	„ „ „
By double „ „ ..	60	„ „	7	„ „ „
By triple „ „ ..	40	„ „	5	„ „ „

In the early days of the beet sugar industry as much as 40 to 42 kg. of coal were used per 100 kg. of beets, and probably the quantity of water to be evaporated was less than now, as the beets were rasped and pressed. The introduction of steam brought down the use of coal to 20 to 25 kg. per 100 kg. of beets.

The employment of coal in beet sugar factories, forming one of the largest expenses, induced constructors to produce new and more economical devices. Rillieux returned to Europe and occupied himself for a time with archæological researches. But on reaching the age of 70 he again gave his attention to evaporators, which, constructed on mistaken principles especially as regards the relative surfaces, did not work at all well.*

---

[*] In reality the difference does not amount to much; but with the utilization of the waste vapours for heating purposes, the idea of multiple evaporation was created.

In Louisiana he had already utilized vapour from the first pan to accomplish the boiling of thick-juice into massecuite. This idea he also applied to the heating of juices, which otherwise were heated by direct steam. The surface of the pan that was to give steam to the heaters, besides heating the following pan, he made correspondingly larger. In a set the vessels all contrive to evaporate equal quantities of water per area of surface. The transmission coefficient gradually sinks towards the last vessel as the viscosity grows, but the larger difference in temperature makes up for this, and the result is that a given area of surface in the first vessel evaporates as much water as the same area in the last one. Thus if 25 kg. are to be evaporated in the second vessel per sq. metre of surface, 25 kg. of steam must be supplied per sq. metre of surface from the preceding vessel, and its surface must be just as large. If we make it larger, it will evaporate 25 kg. as well, leaving a surplus of steam, with which we can heat juice, which steam is used in double effect if drawn from the first vessel, in triple effect if drawn from the second, etc. The quantity evaporated per sq. metre is not thereby affected. If we compare this with the coal economized, it will be noticed that the less water per sq. metre is evaporated, the more economically the original steam is utilized.

The quantity of water capable of being evaporated per hour is as follows:—

In a simple effect 100—125 kg. of water can be evaporated per sq. metre.
,, double ,, 50—60 ,, ,, ,, ,,
,, triple ,, 35—40 ,, ,, ,, ,,
,, quadruple ,, 25—30 ,, ,, ,, ,,
,, quintuple ,, 20—25 ,, ,, ,, ,,

which shows that less water is evaporated per sq. metre, the more economically the initial steam yields its latent heat.

---

* These data are derived from Bolk's "Studies in Evaporation," published in the *Archief Suikerind. Nederl.-Indië.*

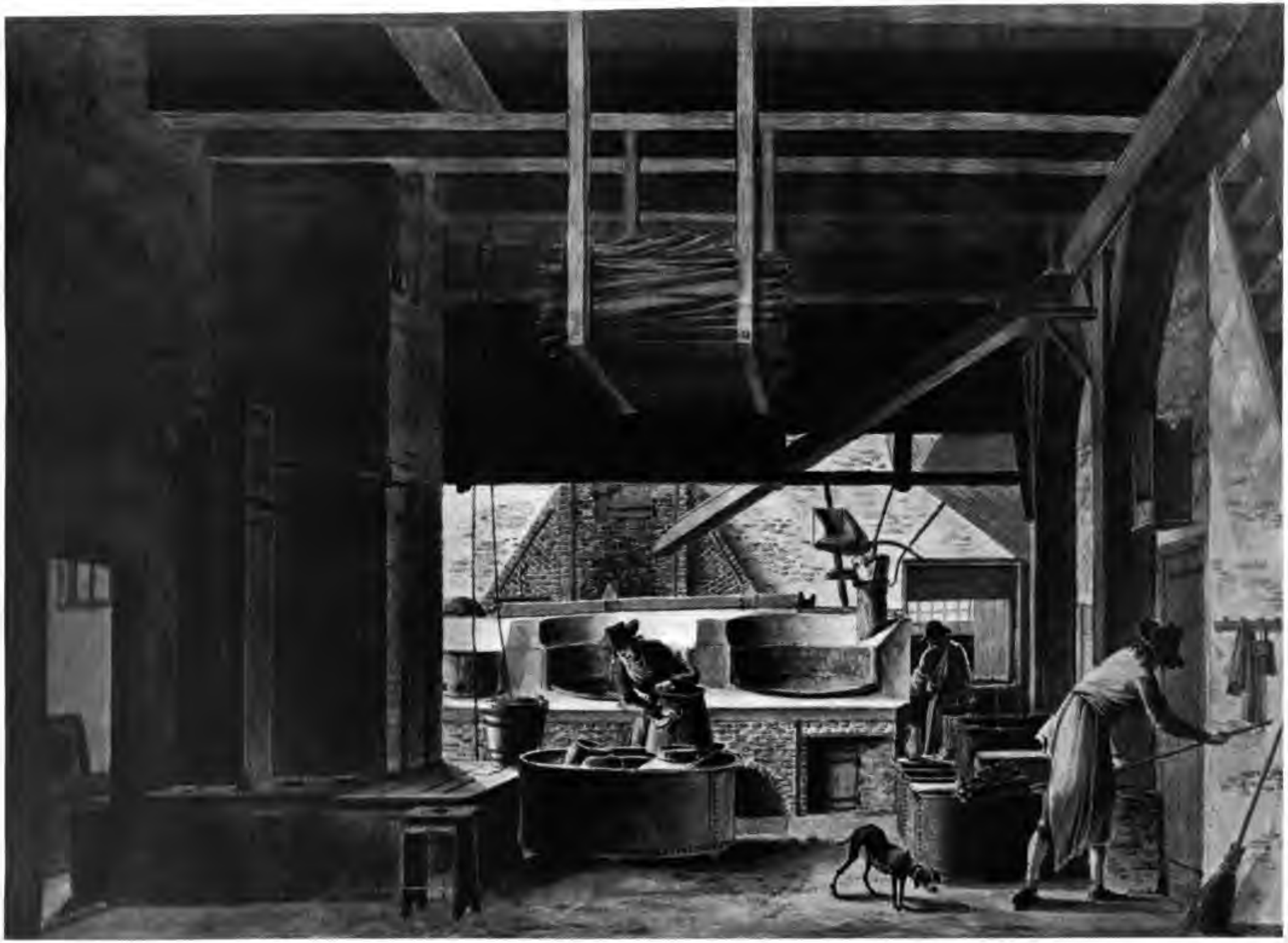


PLATE IV.—INTERIOR OF THE "DE GRANAATAPPEL" SUGAR REFINERY, 1802.

Showing the open pans which served for both evaporation and crystallization.

The economy in the use of steam drawn as "extra" for heating purposes is best shown by calculating the steam needed in a quadruple effect in which all vessels are of the same size (Fig. 7), and that needed in a quadruple effect where the vessels are not equally large (Fig. 8) in order to enable them to supply extra steam for heating purposes. The first pan in this last case is the largest, supplying steam to a heater and to the second vessel; the second vessel is larger than the third, supplying steam to a heater and the third vessel; the third vessel is larger than the fourth, supplying steam to a heater and the fourth; and the steam from the fourth is drawn off to the condenser.

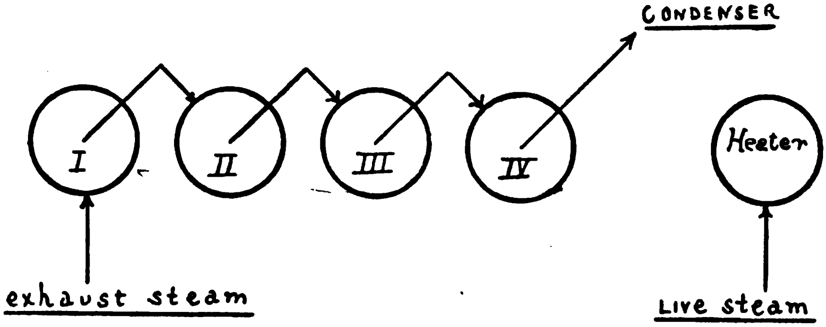


FIG. 7.

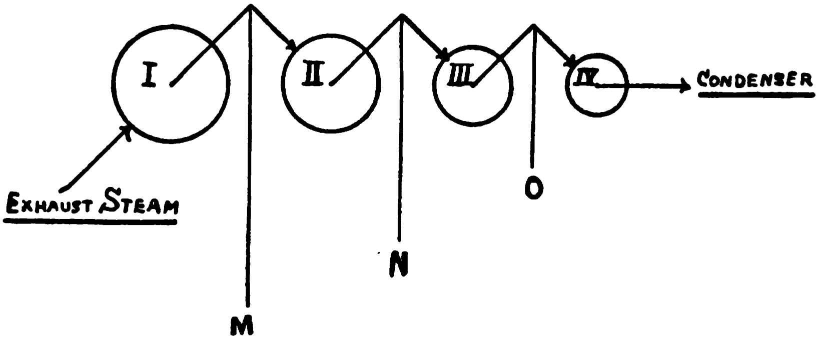


FIG. 8.

*Example I.**

Steam needed $= x$. Steam needed in heaters $= M + N + O$.

Water evaporated $= S$.

$x = \frac{S}{4}$. Total steam needed $\frac{1}{4}S + M + N + O$.

---

* KARL ABRAHAM was the first to simplify calculations in this way; see his work, "Steam Economy in the Sugar Factory."

Example II.

Steam needed in I .. .. .. = x.
" drawn from I for heating = M.
" " II " = N.
" " III " = O.

Evaporated in.. I = x.
" .. II = x — M.
" .. III = x — M — N.
" .. IV = x — M — N — O.

$$S = x + (x - M) + (x - M - N) + (x - M - N - O).$$
$$S = 4x - 3M - 2N - \tfrac{1}{4}O.$$
$$x = \tfrac{1}{4}S + \tfrac{3}{4}M + \tfrac{2}{4}N + O.$$

The difference will be:—

$$\tfrac{1}{4}S + M + N + O - (\tfrac{1}{4}S + \tfrac{3}{4}M + \tfrac{2}{4}N + \tfrac{1}{4}O) = \tfrac{1}{4}M + \tfrac{2}{4}N + \tfrac{3}{4}O;$$

or, in other words, the gain is found by dividing the steam supplied to the heaters by the number of vessels, and multiplying by the number which the vessel, that supplies this extra heating steam, occupies in the order of the set.

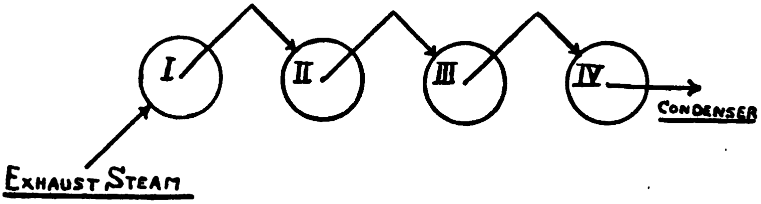


Fig. 9.

The latent heat from the vapour of the last pan was lost in the existing apparatus (Fig. 9), being absorbed by cold water. Hugo Jelinek, a Prague engineer, thereupon utilized this heat for warming raw juice from the battery (Fig. 10.). These heaters thus acted as surface condensers. The economy obtained was the saving of the steam otherwise needed to effect the rise in temperature of the juice. Besides this saving, less injection water was needed in the condenser.

But the motive for finding a more economical construction for evaporating apparatus was not only the saving in steam.

Previous to 1882 the factory engines generally used their full cylinder capacity of steam at each stroke, while the exhaust steam went to the evaporation station. When however, it was found that by cutting off the steam at one-third or one-fourth the stroke the expanding vapour would drive the piston equally well to the end of its stroke, these expansion engines quickly replaced the wasteful older engines. But as less steam was needed for them, less exhaust steam was available, and in cases where the exhaust was insufficient, live steam as well had to be supplied to the first vessel. To utilize this live steam in double effect, at the same time obtaining vapour of sufficiently high temperature to be used in the vacuum pan for graining, **Greiner** and **Pauly** took up the second Rillieux principle. Their first vessel, receiving direct steam, gave all its vapour to a vacuum pan, while the second vessel was in reality the first one of a multiple set, receiving all the exhaust steam available (Fig. 11).

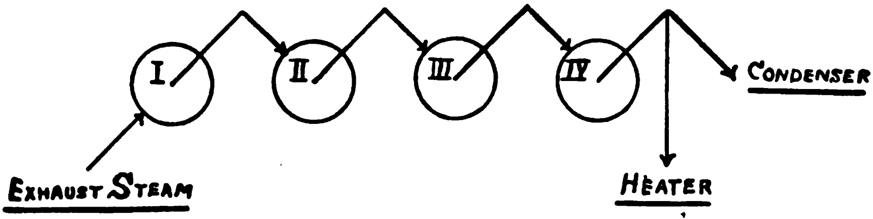


Fig. 10.

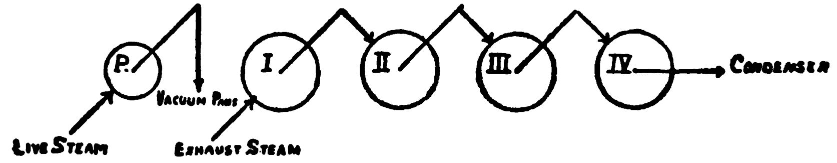


Fig. 11.

The economy achieved is clear; the direct steam is used twice, and the exhaust steam at quadruple effect.

Pauly pans are also used in sets, or connected with other pans, in which case they follow the same laws as described above. When the saving in steam was carried to its maximum limit, designers began to try and improve the speed of operation. Viewed from the point of avoiding the destruction of sugar and the use of higher temperatures, this has really been a success. Different methods were tried to effect a greater speed, *e.g.*, improved circulation devices, thin layers of juice in horizontal apparatus, low juice columns, and, finally, vertical films of juice which climb against the heating surface of tubes 24 to 27 ft. long. LILLIE, YARYAN, SCHWAGER, CLAASSEN, GREINER, and KESTNER are the men who have more or less attained success with their systems.

Specially has KESTNER's system proved a success on account of its speed; but of this we shall have more to say further on when dealing with the several systems. These evaporators are frequently used as pre-evaporators to produce steam for the vacuum pan (in boiling to grain) by direct steam of 140° C. to 150° C.

They are also used in sets, and may then be combined as ordinary members of an evaporating system.

CHAPTER IV.

Comparative Study of Evaporation in the Cane and the Beet Sugar Factory.

When we take stock of a modern cane or beet sugar factory, especially when the complicated machinery is in full swing and engines of all sorts are in motion, it is hard to imagine that once things were entirely different.

The primitive methods of manufacturing sugar from cane were copied from the natives of different tropical countries, and for many years, even in the larger factories belonging to Chinese and European owners in Java, the old open pans were adhered to, as well as the primitive mills driven by oxen. While the cane sugar industry was still at a very early stage of evolution, the beet sugar industry made its début. Naturally enough, the primitive methods of the tropics were here likewise copied, and in beet as well as in cane factories for years to come the owners were radically opposed to anything driven by steam. As an example, the air pump did not find a favourable reception; manufacturers found it too complicated, and so were very reluctant to adopt it, thus retarding its development and practical application.

In the end, competition compelled the conservative owners either to change their procedure or else to close down. Not only did they have to meet competition amongst themselves, but cane had soon enough to fight against beet, the development of which was greatly encouraged in various ways.

In both industries the question of fuel was and still remains of great economic importance. In cane factories, the residue of the cane used to be dried on the field, the dried *bagasse*, as it is called, serving as fuel. Dried cane-leaves, or wood or coal, had to be supplied in addition, notwithstanding that the mills were not then efficient, and maceration or imbibition was not practized. When steam-driven mills replaced the older animal power, and steam was substituted for open fire to evaporate the water from the juice, it was only natural that the exhaust steam which then became available should be used instead.*

---

* Here again, it was RILLEUX who first used exhaust steam in the first body of an evaporator.

In the beet factories the work was at first entirely done by manual labour,* except the rasping of the beets, the motive power for which was derived from horses. But the hand-presses were soon replaced by hydraulic ones, and these in turn by diffusion batteries.

That such a good use could be made of the great amount of exhaust steam available makes it clear that condensing engines, such as are found in steamships, never gained an entry into sugar factories.

In comparing the two industries, the evaporation station offers the greatest resemblance of the series. Yet the difference which does exist between cane and beet juice affects the construction of even this station. Thus, besides being of interest to the chemist, the following points comprise differences worthy of notice by the engineer, as they influence the construction of the evaporation plant, and should be studied before any new design is attempted:—

1. The *quantity* of water to be evaporated, depending on the limits of the Brix reading.
2. *Incrustations,* which gradually deposit from the concentrating juice in tubes.
3. *Incondensible gases,* and their regular withdrawal from the steam drums.
4. The *quantity of exhaust steam* available.

THE QUANTITY OF WATER TO BE EVAPORATED.

(A) In Beet Sugar Factories.

As already pointed out, the concentration is divided into two stages:

1. Concentrating thin-juice to thick-juice in the vacuum apparatus.
2. Concentrating thick-juice to massecuite in the vacuum pans.

The *total quantity* of water to be evaporated is the very first thing we have to know, whether a new apparatus is to be designed or an old one merely enlarged; also when we wish to control the efficiency of an apparatus, the quantity of vapour to be condensed, the condensed water to be expected, etc., must be calculated. The measure, which expresses the limits between which lies the quantity of water evaporated, is the Brix of the hydrometer reading which is intended to express the percentage of solids present. These limits are comprised in the designations—*Brix of the thin-juice, Brix of the thick-juice,* and *Brix of the massecuite.*

---

* See J. J. REESSE, "De Suikerhandel van Amsterdam tot 1813."

The Brix of the beet thin-juice depends chiefly on the juice drawn off *i.e.*, the litres of raw juice obtained from 100 kg. of slices. As this juice drawn off varies from 100 to 120 litres, the Brix of the thin-juice varies accordingly.

Besides the juice drawn off, the form in which lime is added will slightly influence the Brix. In beet factories either dry lime or milk-of-lime can be used.* When the lime is added as milk-of-lime, the water used to sweeten off the lime-cakes is used for slaking. The quantity of lime (and also of milk-of-lime) varies slightly. In well-conducted factories the juice drawn off, and the dilution by sweetening-off water or milk-of-lime, are limited to what is strictly necessary. Taking a sample from actual practice, we find:

Beets worked per minute, 761 kg.
Juice drawn off, 103 litres per 100 kg. of beets.
Specific gravity, 1·061.
Sweetening-off water, 16·9 per cent. on beets.
Brix of thin-juice, 12·98°.

The limit of the Brix of the thick-juice is fixed by various practical considerations. Of course, in general, it will be so much more economical to make this limit as high as possible; in an evaporating set 1 kg. of steam introduced into the first body evaporates 3 to 4 kg. of water; while the steam introduced into the vacuum pan evaporates in single effect at best; or when this steam is drawn from a first body of an evaporation set, or from a pre-evaporator, in double effect.

With increasing concentration and lower temperature, the viscosity rises considerably, as pointed out in Chapter II. The greater viscosity prevents a speedy transmission of heat. So as to lessen the viscosity (which is not favourable for good graining), the thick-juice is sulphited and filtered. This also puts a limit to high concentration: too heavy a juice cannot be filtered.

---

* In cane factories dry lime cannot be used, as cane contains glucose, which would form dark decomposition products on slaking with the juice.

The fear that the juice will crystallize in the last body or in the pipes is, it may be remarked here, somewhat exaggerated.

At the prevailing vacuum in the last body of about 600 mm. (23⅝ inches), a sugar solution boils at 61·6° C. (CLAASSEN). At this temperature 2·91 weight-units of sugar can be dissolved per 1 weight-unit of water (HERZFELD). At 65° Brix, the percentage of water is 35. In a saturated condition 2·91 × 35 = 101·8 parts of sugar can be dissolved per 35 parts of water, corresponding to a percentage of sugar in the thick-juice of 74 per cent. The sugar percentage, however, is actually about 60, so that it is not yet saturated and is far from the supersaturation point. For beet juices this last point lies higher than in cane juices, the former being not so easy to "grain." Of course the point at which the first grain is formed is above saturation point, but the purer the juice the less is this so. When making a strike with thick-juice of 91·3° purity, the author tested the Brix just before forming grain. At the reading the juice showed 85·47° Brix, 78·10° polarization, 91·3° purity, and 78° C. temperature. In 14·53 parts of water were dissolved 78·10 parts of sugar, equal to 5·37 parts of sugar per one part of water. In a sugar solution of 78° C., 3·52 parts of sugar are dissolved per one part of water (CLAASSEN).

When the first grain was made, $\frac{5{\cdot}37}{3{\cdot}52} = 1{\cdot}5 \times$ the saturation quantity was present. The factor 1·5 represents the supersaturation.

BRUNINGS has calculated some factors for different factories:—

System.	Temperature of Graining.	Coefficient of Supersaturation.	Product.
Lenze-Freitag	89°	1·29	Raw sugar.
,, ,,	92°	1·30	,, ,,
,, ,,	88°	1·42	,, ,,
Greiner	78°	1·29	,, ,,
Coils	76°	1·74	White sugar.

The limit actually reached may be taken as about 65°. Many factories, however, cannot attain this figure because their heating surface is too small.

The thick-juice is drawn into the vacuum pan to be further concentrated. High concentration means a high yield in crystals, even if the massecuite must be diluted with syrups from a previous strike, in order to enable it to flow into the crystallizer.

When white sugars are being made, the massecuites are kept pure and the concentration cannot be driven so far. For raw sugar the massecuite should be concentrated to 96° Brix. The quantities of water to be evaporated can thus be worked out, if we make an extra allowance for water evaporated in the second product pan. This quantity depends on the process followed as well as on the dilution.

In the example from practice mentioned above, the quantity to be evaporated was:

Brix of the thin-juice	12·98°
Brix of the thick-juice	62·86°

Weight of the thick-juice $= \frac{12 \cdot 98 \times 126 \cdot 18}{62 \cdot 86} = 26 \cdot 05$. % on [illegible]

Water evaporated $= 126 \cdot 18 - 26 \cdot 05 = 100$ kg. per 100 kg. of beets.

Taking another case, the following figures are more general, and include normal losses in the battery and filter-press stations.

	Per cent.
Sugar in beets	15
Loss in battery (known)	0·35
,, ,, (undetermined)	0·30
Total battery loss..	0·65 on beets.

Sugar in raw juice.. .. $15 - 0 \cdot 65 = 14 \cdot 35$ per cent. on beets.
Sugar in lime-cake .. .. 0·75 per cent.
Weight of lime-cake .. .. 10 per cent. on beets.
Loss in lime-cake .. ..0·075 on 100 kg. of beets.
Sugar in thick-juice .. $14 \cdot 35 - 0 \cdot 075 = 14 \cdot 275$ per cent. on beets.
Sugar in thick-juice .. .. 58·12 (if Brix = 62·5° and purity 93·0).

Quantity of thick-juice .. $\frac{14 \cdot 25 \times 100}{58 \cdot 12} = 24 \cdot 5$ kg. on 100 kg. of beets.

Juice drawn off 106
Specific gravity of raw juice .. .. 1·06
Sweetening-off water .. .. 120 per cent. on lime-cake.
Quantity of thin-juice..$106 \times 1 \cdot 06 \times 12 = 124 \cdot 36$ kg. per cent. on beets.
Quantity of thick-juice.. .. ..24·5 ,, ,, ,,
Quantity of water to be evaporated .. about 100 ,, ,, ,,

Assuming the average Brix of the massecuite to be 96°, the quantity of water to be evaporated in the first-product pan will be:

Brix of thick-juice .. .. .. 62·5°.

Quantity of thick-juice	24·5	per cent. on the beets.
Quantity of massecuite	16·0	,, ,, ,,
Water evaporated	8·5	,, ,, ,,

The quantity remaining to be evaporated can only be hazarded, say 2·5 per cent. on the beets, making a total of 10 per cent. on the beets.

(*B*) *In Cane Sugar Factories.*

As already remarked, the supersaturation factor needed to effect graining is lower for cane than for beet juices, in other words, cane-juice "grains" sooner, and also more easily. As a direct result the maximum Brix of the thick-juice is somewhat lower than is the case with the beet juice.

Considering the Brix of the thin-juice first, we notice that it fluctuates more than the Brix of beet thin-juice, depending chiefly on:—

1. Method of *Extraction* (milling, diffusion, combined milling and diffusion, maceration or imbibition).
2. Method of *Liming* and *Manufacture* (defecation, sulphitation, single or double carbonatation).
3. Content of *Cellulose* (influence of the seedling canes).

When designing an apparatus, it is worth while to take these factors into account, especially the two first items.

1. *The Method of Extraction.*

The most prevalent method, in fact we may call it the normal one, by which the juice is extracted from the cane is by a series of rollers, crushers, and mills.

In a few special cases, where factors prevail which justify a still greater extraction at greater cost of fuel, diffusion batteries, either alone or combined with mills, are met with.

In competing with the beet industry, cane sugar factories have strengthened their position by improvements in the yield of cane and in the method of manufacture. As compared with what has been accomplished in the case of the beet, however, the sugar content of the cane has remained practically constant.

Thus the principal factor which has influenced the financial results to such an extent that the cane industry has now no fear whatever of its competitor, has been the extraction of a higher percentage of the sucrose present in the cane. This has been accomplished in the first place by reducing the loss of sugar in the bagasse. With bad mills and no dilution, losses in the bagasse amounting to 12 per cent. of the total sugar present in the cane were frequent in the old days. Better mills, aided by crushers and by imbibition by cold or hot water, have reduced this loss to 7 to 9 per cent. of the sugar which is present in the cane. In the few factories which extract a still greater percentage by means of diffusion batteries or a combination of battery and mills, the loss in the bagasse is still smaller.

Prinsen Geerligs* gives the following proportions of juice expressing. Triple pressing without imbibition, using purple cane (second ratoons), was employed :—

	Per cent.
Pressed from 1st mill	64·50
,, ,, 2nd ,,	5·50
,, ,, 3rd ,,	2·13
Total	72·13

In triple pressing with steam imbibition, using purple cane (first ratoons) :—

	Per cent.
Pressed from 1st mill	64·31
,, ,, 2nd ,,	8·00
,, ,, 3rd ,,	4·52
Total	76·83

In triple pressing with 20 per cent. of cold water imbibition, using purple cane (plant cane) :—

	Per cent.
Pressed from 1st mill	66·50
,, ,, 2nd ,,	12·15
,, ,, 3rd ,,	4·51
Total	83·16

In modern factories, the quantity of imbibition water fluctuates from 12 to 16 per cent. The sugar content of the bagasse will then be about 4 to 4·5 per cent. To raise the quantity of imbibition water unduly increases the non-sugar in the diluted juice, as well as the quantity of water to be evaporated.

---

* "Cane Sugar and its Manufacture," pp. 121-122.

FRANCIS MAXWELL[*] gives the following averages in his study on heating surfaces:—

Entering mills, 113 kg.

Cane, 100 kg. Imbibition water, 13 kg.

Cellulose, 11 kg. Original juice, 89 kg.

Leaving mills, 113 kg.

1st mill ..	67 kg.	of original juice.
2nd „ ..	5 kg.	„
3rd „ ..	9·97 kg.	„
	7·63 kg.	of imbibition water.
Total ..	89·60 kg.	of mixed juice.

Bagasse, 23·40 kg.

Cellulose..	11 kg.
Original juice	7·026 kg.
Imbibition water ..	5·374 kg.
Total ..	23·40 kg. of bagasse.

Evidently the imbibition water is given after the second mill. The general method in most Java factories is imbibition of hot water after the first mill.

The sugar loss may be calculated as follows:—

Entering mills, 113 kg.

Cane, 100 kg. Imbibition water, 13 kg.

Cellulose, 11 kg. Water, 75·67 kg. Sugar, 13·33 kg.

Leaving mills, 113 kg.

Mixed juice, 89·6 kg. Bagasse, 23·4 kg.

Sugar, 12·277 kg. Water, 77·323 kg. Cellulose, 11 kg. Sugar, 1·053 kg. Water, 11·347 kg

In this case 92·1 per cent. of the sugar introduced goes into the measuring tank, and 7·9 per cent. is lost in the bagasse.

Dealing with the quantity of juice extracted in diffusion batteries, we learn from PRINSEN GEERLIGS that 98 litres of juice were drawn from 100 kg. of cane at a trial in Wonopringo, Java. The specific gravity being 1·0609, this makes 104 per cent. of cane by weight, to which the milk-of-lime must be added.

---

[*] *International Sugar Journal*, 1910, 561.

When mills are combined with a battery, the cane first passes through a crusher. The crushed cane next goes through two mills, which together with the crusher press 60 to 65 kg. of mixed juice per 100 kg. of cane. The bagasse from the second mill contains about 8 per cent. sugar. A battery extracts the largest part of this sugar, leaving about 0·5 to 1 per cent. of sugar in the bagasse. This wet bagasse is relieved of its water content by a third mill, while the bagasse containing about 50 per cent. of water goes to the boilers.

100 kg. of cane is passed through the mills.	65 kg. of juice.	
	35 kg. of bagasse enters the battery.	32 kg. of juice. 35 kg. of bagasse.

The total quantity of mixed juice from crusher, mills, and battery will be about 100 per cent. on the cane.

2. *Method of Liming and Manufacture.*

The mixed juice, composed partly of the original cane juice and partly of imbibition water, is limed exclusively with milk-of-lime. As already mentioned, dry lime cannot be used here because the heat generated by the slaking process would decompose the glucose, thus producing a dark-coloured juice.

A marked difference from the beet industry as regards liming is the quantity of lime, in the form of milk-of-lime, used per 100 kg. of cane. Beet juices are limed with 2·5 to 3·5 per cent. of lime, and the liming has very little influence on the Brix of the thin-juice.

With cane juice, on the other hand, the quantity of lime added attains wider limits, depending on the process of manufacture which is followed.

As shown in the following table, the carbonatation process requires the most lime. It is the method chosen by many white sugar factories, which are recompensed by the higher yield and quality of the product for the larger expense involved:—

	Litres of Milk-of-lime at 15 Bé added per 1000 litres of Cane Juice.	Calcium Oxide (CaO) added.	Calcium Oxide (CaO) per 100 kg. of Cane.*	Litres of Milk-of-lime per 100 kg. of Cane.
Defecation	3 to 5	444-740	0·037-0·062	0·34
Sulphitation	10	1480	0·125	0·85
Single Carbonatation	70	10360	0·88	6·00
Double „	100	14800	1·25	8·00

---

* Assuming that 100 kg. of cane yield 90 kg. of juice of 1·06 specific gravity.

The average Brix of the thin-juice will be higher than the Brix of beet thin-juice, fluctuating more under the different processes.

In defecation factories 15° to 17° represents an average Brix. The press-cakes are not sweetened off, as they are too slimy, and the quantity is but small.

In cane carbonatation factories when the press-cakes are sweetened off the water will not affect the Brix to such an extent as with beet juices, as the quantity of lime-cake is smaller, although the Brix of carbonatation factories is lower than that of defecation factories.

The thick-juice of cane factories, as already remarked, is not so concentrated as in beet factories. Probably the glucose plays a rôle here, and at least partly may account for the fact that cane juice grains more quickly and easily and at a lower Brix than beet juice.

Prinsen Geerligs* gives 60° C. as the temperature of graining with a Brix of about 80° to 81°. The same author gives supersaturation factors for juices at the point of graining. Many of them are much lower than those known for beet juices.

1·15	1·09	1·10	1·24	1·36	1·10	1·03
1·13	1·40	1·06	1·06	1·20	1·23	1·06
1·14	1·28	1·37	1·21	1·27	1·08	1·28
1·40	1·46	1·04	1·07	1·18	1·57	

Another reason, in the case of defecation factories, is that the thick-juice is boiled up and left to settle. The quicker it settles, the smaller will be the loss of sugar through the high temperature. Very highly concentrated juice will be more viscous and will settle more slowly.

The average Brix attained in 130 Java factories in 1910 was 54·02°. In 1911 the average Brix from 111 defecation factories was 53·56°, and from 16 carbonatation factories, 51·53°.

These averages are lower than the Brix reached in beet factories (the average Brix of Dutch beet factories in 1911 was 63·64°); but in 24 Java factories the Brix varied from 58° to 63°, so 60° does not seem too high for cane thick-juice, while for massecuite the same limit may be taken as for beet factories, viz., 96° Brix.

---

* "Handboek ten dienste van de suikerriet-cultuur en de rietsuikerfabricage," 1911, p. 275.

3. *Content of Cellulose.*

In the beet the cellulose content, varying from 5 to 6 per cent., does not exert any influence at all on the quantity of juice which is extracted. With sugar cane the cellulose content used to be fairly constant, and amounted to 12 per cent. on the cane. However, the new seedling varieties lately introduced show marked differences in their cellulose percentages; and evidently those with more cellulose will contain less juice. The following series is given by Prinsen Geerligs,* and covers a range of 6 per cent.

Seedling No. 100	9·77	Seedling No. 139	14·16
Black Cheribon.. ..	10·38	Seedling No. 33a ..	15·59
White Manilla	11·80	Seedling No. 36 ..	15·72
Seedling No. 247 ..	13·85		

These higher percentages must not be considered as averages. When a factory has not too much fuel, such canes are useful for increasing the quantity of bagasse. For normal limits 10 to 15 per cent. should be taken.

Recapitulating, the quantities of water to be evaporated will be as follows :—

Beet Factories.

Thin-juice obtained, 126 kg. per 100 beets; concentrated from 13 to 62·5° Brix; water to be evaporated, 100 kg. per 100 of beets.

Cane Factories.

Quantity of thin-juice per 100 of beets.

	Mills with imbibition. Per cent.	Diffusion battery. Per cent.	Mills and battery. Per cent.
Defecation	90	104	100
Carbonatation	97	111	107
Brix of thin-juice to Brix of thick-juice.			
Defecation	15 to 60	14 to 60	14 to 60
Carbonatation	14 to 60	13 to 60	13 to 60
Water to be evaporated per 100 of cane.			
Defecation	67·5	79·8	77·0
Carbonatation	74·4	87·0	84·0

These quantities must not be taken as strictly exact, for they will fluctuate according to the cellulose content, the imbibition, the efficiency of the mills or battery, etc.

---

* "Cane Sugar and its Manufacture," p. 50.

INCRUSTATIONS AND THEIR INFLUENCE.

From a theoretical standpoint it would be perhaps possible to obtain thin-juice entirely free from lime, in both cane and beet factories. But practically by whatever form of extraction and whatever process of clarification the thin-juice is obtained, the latter contains lime salts (of phosphoric, oxalic, carbonic, and sulphurous acids), silica, iron and alumina. These non-sugars, soluble in the hot thin-juice in which they are present in small percentages, become partly insoluble as the concentration increases and the temperature descends.

For the designer, of the beet as well as of the cane factory, their interest lies in their very low conductivity (see *Chapter I*) which hampers the transmission of the heat. In cane factories cleaning during the campaign is more or less frequently practised, while in beet factories the author has run through a whole campaign without cleaning being necessary. In both cases, however, the tubes transmit the greatest quantity of heat in the beginning when they are perfectly clean; their capacity for transmitting drops slowly towards the end, and this factor must be taken into account when calculations are made for the heating surface, an addition of 10 to 15 per cent. to the area being advisable. The chemist's task is to study the conditions which will lead to as little deposit as possible and a profitable field of investigation remains still open.

Calcium sulphite, which is liable to be formed when sulphitation is practised, is more soluble in hot solutions than in colder ones.

In a 10 per cent. sugar solution the following amounts are soluble at different temperatures (Centigrade):—

20°	30°	40°	50°	60°	70°	80°	90°	100°	
0·183	0·144	0·140	0·075	0·035	0·033	0·012	0·010	0·006	per cent.

Calcium oxalate becomes decreasingly soluble the greater the concentration.

Sugar per cent.	Calcium oxide (CaO) per cent.	Calcium oxalate per cent.
7·1	1·960	0·0520
20·1	2·058	0·0549
32·2	1·790	0·0229
43·2	1·560	0·0042
50·0	0·773	0·0000

As regards the influence exerted by the scale, the author lately tried to throw some light on the subject.* But as then stated, the factors influencing the deposit of scale are so various and inconstant, that no basis whatever can be given; even the same factory will show different amounts. That a better control and thorough study of the deposit and its factors is beneficial, and may lead to appreciable steam economy, is shown clearly enough in the article just cited.

The factors which influence the formation of scale are :—

(1) The nature of the non-sugars originally present in beet or cane.
(2) The system of manufacture selected.
(3) The control of the system.
(4) The impurities present in the lime.
(5) The rate of the evaporation.
(6) Inefficient filtering of the thin-juice.

In beet as well as in cane *organic acids*—oxalic in the first place, but also citric acid—form calcium salts in the liming process. These lime salts, soluble in thin-juice, are gradually deposited when the concentration rises and the temperature falls.

The *system of manufacture* will influence the formation of deposit still more. Those factories, which manufacture white sugar direct from cane or beet, make use of sulphurous acid chiefly to bleach the juices. Here calcium sulphite will be formed and deposited, partly in the scum and partly as scale in the tubes.

That the *control* will exert its influence does not need to be emphasized; too little or too much carbonic acid, the omission to boil up in the second carbonatation, too low an alkalinity in the first carbonatation—all these mistakes will reveal themselves in the production of scale.

The lime which is used in sugar factories often contains impurities. As pure a lime as possible is a desideratum, since the iron, alumina, silica, and magnesia found in incrustations may be ascribed to the use of impure lime-stone.

The rate of evaporation is of unquestionable importance. The quicker the juice passes through, the less chance there will be for the calcium salts to form scale.

---

* *International Sugar Journal*, 1912, p. 149.

Saillard has tested a Kestner evaporator at Noyelles-sur-Escaut, France. The pan had a capacity of about 430 litres (94·5 gallons) of juice. By drawing off the contents when evaporation was progressing (the juice entry and exit being closed at the same moment), the quantity of juice was only 125 litres (27½ gallons) per minute. The juice delivered by the Kestner in the ordinary run was 227 litres (50 gallons), thus showing that the syrup remained in the Kestner less than one minute.

Similar experiments with ordinary evaporation sets will show a much slower run. At so rapid a rate, hardly any scale is deposited.

At the Vierverlaten factory, Holland, the quantities of scale deposited were weighed; but as the pans were first boiled out with carbonate of soda and hydrochloric acid, the actual quantities must have been greater.

Kg. of Beets.		I. kg.	II. kg.	III. kg.	IV. kg.	Total. kg.
66 million,	1st set	—	—	—	—	43
	2nd „	—	—	—	—	43
62 „	1st „	60	9	11·5	19·5	100
	2nd „	62	10	7·0	23·0	102
57 „	1st „	45·2	10·5	15·0	24·0	94·7
	2nd „	44·5	9·5	8·2	20·0	82·2
78 „	1st „	15·0	7·0	21·0	81·0	124
	2nd „	15·0	15·0	11·5	87·5	129
78 „	1st „	24·5	13·5	23·0	96·0	157
	2nd „	24·0	14·0	20·0	99·0	157

The effect on the use of steam in the first vessel will be seen in the following figures, representing averages from 10-day periods :—

	Kg. of Water evaporated by 1 kg. of Steam.		Kg. of Water evaporated by 1 kg. of Steam.
Beginning of campaign.. ..	3·3		2·8
	3·45		3·3
	3·1		2·0
	3·0		2·7
	2·76	End of	
	3·2	Campaign	2·6
	3·4		

The last factor, *inefficient filtering*, should not occur; but when a filter-press is being emptied, part of the lime-cake may escape into the juice-gutter. The juice which flows from the emptied press will carry along these solids, and if a special filter is not provided, they will be deposited in the tubes of the first vessel.

Besides these incrustations in evaporation bodies, inside the tubes in vertical apparatus and outside the tubes in horizontal ones, the tubes belonging to juice-heaters become incrusted with deposits of varying composition. Raw beet-juice deposits both pulp and albumen. Even if a pulp-catcher be provided, some fine pulp gets through, and, together with albumen, forms a thick layer in the tubes. The best remedy is to provide enough heaters to make it feasible that each day one of them at least can be closed down to be cleaned. And speed will prove beneficial; thus, heaters with a 16-fold circulation will not incrustate so quickly as those where the juice does not attain such a rapid passage.

HAZEWINKEL* reports the existence of deposits in cane juice-heaters, and states how they are formed. In the sulphitation-defecation process they also cause trouble.

He explains the reaction as follows:—

In Liming:

Potash salts + lime = lime-salts + 2 KOH (potash).

In Sulphuring:

Lime salts + 2 KOH + SO_2 (sulphurous acid) = lime salts + K_2SO_3 (potassium sulphite) + H_2O (water) + $CaSO_3$ (calcium sulphite).

When Heated:

Lime salts + K_2SO_3 = $CaSO_3$ + potash salts.

INCONDENSIBLE GASES AND THEIR ELIMINATION.

Every factor which prevents or retards transmission of heat should be avoided. In this respect cane and beet are perfectly alike. Nitrogenous compounds, however, are a constant constituent of the beet, and *ammonia*, a product of the decomposition of these substances, passes into the steam-drum together with the juice vapour. The condensation will absorb this ammonia in part, but the quantity

---

* *International Sugar Journal*, 1911, 158.

(according to CLAASSEN, 10 to 20 grms. per 100 kg. of beets) seems to be too large to be absorbed completely, so some gathers in the upper portion of the steam drum. Carbonic acid seems to be liberated from the juice as well; while air, entering by leaks, mixes with it, and in combination with ammonia attacks the brass or copper, making numerous tiny holes. Cane juices do not yield ammonia, hence the quantity of incondensible gases in this case is smaller.

As the conductivity of air is very low, a cushion of air will prevent contact between the steam and the heating surface. Besides, any piercing of the tubes must lead to loss of sugar. The so-called "ammonia tubes" are designed for the purpose of withdrawing these gases completely. While they are necessary for good transmission, their diameter must be a minimum, especially if the ammonia tubes of each pan pass separately into the condenser. Whatever steam is mixed with these gases is also passed out; and in order to avoid such losses, the tubes are often laid down from steam-drum to vapour space. The tubes of the last pans must be larger as the gases keep on returning until they leave the steam drum of the last body.

THE QUANTITY OF EXHAUST STEAM AVAILABLE.

In our historical sketch we have pointed out the relation that exists between the type of engine used in a sugar factory and the necessity for evaporating large quantities of water; complicated machinery, like the triple-expansion engine which we find in steamships, for obvious reasons has never been introduced into the sugar factory. The introduction of expansion devices coincides with the bringing into force of Rillieux's second principle. Evidently the old type of engines yielded so much exhaust steam that sufficient was available not only for evaporation but also for heating purposes. When the quantity was more restricted, it became more economical to draw juice vapour from the first and second pans.

The quantity of exhaust steam was still further limited by the concentration of power. The many scattered engines, each with its steam losses, were united into belt-driven or motor-driven machines, receiving their motion from a central shaft connected to the main engine or from a main electric generator. Electrical motors have especially brought about a great change, as they can replace wasteful steam-pumps and engines; again the separate air-pumps attached to the evaporation station and vacuum pans were replaced by the central condenser with one dry air pump, with a consequent saving in steam. Finally, the quantity of exhaust steam proved insufficient to supply the evaporation plant, and live steam had to be supplied as well.

The idea of the pre-evaporator lies chiefly in separating the live steam and the exhaust, the first being utilized in double effect. A greater quantity can be used than when the two are mixed, as the resistance of the steam valves must be limited to about 22 lbs. per sq. in. up to 30 lbs., or if the boiler pressure be high, 150 lbs. per sq. in. for instance. Moreover, the pre-evaporator helps in the concentration, leaving less water to be eliminated in the rest of the evaporation set, and thus ensuring that whatever exhaust steam is available will be sufficient for that quantity.

It is the introduction of the pre-evaporator which has reduced the total steam consumption of a beet factory from 65 to about 55 per cent. of beets.

In this respect, however, a difference must be noted between beet and cane. Making every allowance for the quantities of exhaust steam, produced by more or less ingenious factory designs, the cane factory will in general have more exhaust steam available than the beet factory. In giving the total horse-power required, it must be remembered that factories of the same beet capacity will require different amounts, due solely to the difference in design. Where capacities vary, the largest factory will as a rule need the least horse-power per cent. of beets.

The author had occasion to take power diagrams in the fairly up-to-date factory of Vierverlaten. The filter-press pumps, washing tanks, beet and pulp elevators, slicers, slice conveyors, lime mixers, and pulp presses were all driven from one central shaft turned by a two-cylinder main engine. Electrical current for power is not used inside this factory, but outside an electric gantry crane for unloading beets derives its current from a generator in the factory.

The total horse-power needed is as follows :—

	I.H.P.
Main engine (two cylinders, each 125 H.P.) ..	250
Air pump (dry)	68
Water pumps (two, each 30 H.P.)	60
Gas pump	40
Weston centrifugal pumps	76
Crystallizer engine	15
Raw juice pump	29
Boiler feed pumps (two at 6 H.P.)	12
Dynamos	60
Repair shop	9
Total	619

This total will be more than the actual I.H.P. developed on the average, since the electric light dynamos run only part of the day, as does the repair shop engine; while the Weston water compressors are run alternately.

On the other hand, this factory does not dry any pulp, which should be part of the routine of a modern factory, and will require some power yielding exhaust steam.

The pumps, be it observed, are not the rotary type, such as are specified in modern designs*; in modern factories rotary pumps moved by an electrical motor will require still less power to drive; so to take 600 I.H.P. for a factory of about 1200 tons capacity will not be far from the average, though individual cases differ according to the equipment and the efficiency.

The steam consumption of these engines is obviously not identical, it is smallest in the main engine and the other large types, equipped with cut-off valves; larger in the pumps and specially large in the Weston water-compressors. If we count on 20 kg. (44 lbs.) of steam as an average per horse-power per hour, the quantity of exhaust steam available will be $\frac{600 \times 20}{60} = 200$ kg. (440 lbs.) per minute. With 10 per cent. loss by condensation and radiation, 180 kg. (396 lbs.) per minute is available per 833 kg. (1832 lbs.) of beets, making 21·6 per cent.

---

*Puttershoek factory is now fitted solely with rotary compartment pumps.

Compared with a cane factory, the percentage is larger. Recent records* give a case of a factory where the capacity was 21·5 tons of cane per hour, or 5160 tons per 24 hours. The I.H.P. based on indicator diagrams was summarized by H. G. Moll as follows:—

	I.H.P.
No. 1 mill engine	61·34
No. 2 „ „	64·10
No. 3 „ „	67·89
No. 4 „ „	70·37
Total	**263·70**
Vacuum Pumps—	
Multiple effects	16·30
No. 1 pan	20·46
No. 2 „	21·78
Total	**58·54**
Centrifugal engines	28·25
Cane conveyor engines	8·00
Bagasse „ „	6·50
Electric light	12·00
Repair shop	10·00
Total	**64·75**
Main water pump	18·2
Multiple condensation pump	5·0
Juice pump	3·0
Molasses	2·5
Boiler feed-pump	10·0
Total	**38·7**
Grand Total	**425·69**

for **5160** tons of cane worked up per 24 hours.

For a 1200-ton factory, the I.H.P. needed will be about 800, and this will require 266 kg. (585 lbs.) of steam; assuming the same measure as to use of steam, 240 kg. (528 lbs.) of exhaust will be available for the multiple effect, making 28·8 per cent.

---

* *International Sugar Journal*, 1912, 436.

The beet factory, evaporating 100 per cent., has available 21·6 per cent. of exhaust steam, while the cane factory, evaporating 65 per cent., has available 28·8 per cent. of exhaust steam.

Glancing at these values, we see that the beet factory requires live steam in any case, while the cane muscovado factory has enough exhaust steam to supply a multiple effect, even if juice vapour is drawn from one or two pans.

An exact knowledge of the amount of exhaust steam is, however, essential in both cases. On this basis, and given the amount of water to be evaporated and juice to be warmed up, every case has to be studied individually. It will not be economical to use a large part of the exhaust steam for warming purposes in simple effect, a small quantity of live steam by means of a pre-evaporator in double effect, and the rest of the exhaust in quadruple effect.

When making these calculations, the effect of steam must always be worked out. If no extra juice vapour be drawn from first or second vessels, the effect is simply: $x = \frac{s}{p}$ where S = water to be evaporated and p = number of pans.

If S be 100 per cent. and $p = 4$, $x = \frac{100}{4} = 25$, thus, 25 kg. (55 lbs.) of steam evaporates 100 kg. (220 lbs.) of water, or 1 kg. of steam evaporates 4 kg. of water.

If extra steam is drawn from the first pan, the result may be reckoned as follows, taking our case from practice :—

Raw juice to be heated, $103 \times 1{\cdot}061 = 109{\cdot}3$ per cent. of beets.

1 kg. of steam will yield $607 - (0{\cdot}7 \times 100) = 537$ calories.

Therefore calories required: $109{\cdot}3 \times (78 - 50) = 3060$.

Juice vapour required: $\frac{3060}{537} = 5{\cdot}7$ per cent., so the first pan must evaporate $5{\cdot}7 + \frac{100 - 5{\cdot}7}{4} = 29{\cdot}3$ per cent.

Steam required: $x\,(607 - 0{\cdot}7 \times 112) = 29{\cdot}3 \times (606{\cdot}5 + 0{\cdot}3 \times 104 - 88) = 30{\cdot}4$ kg., and 1 kg. of steam evaporates $\frac{100}{30{\cdot}4} = 3{\cdot}29$ of water.

But, as in modern factories still more juice vapour is drawn off, the result is often yet lower, 3 or less kg. of water per kg. of steam.

In general, the installation of a pre-evaporator will be more satisfactory in a beet than in a cane factory. The steam economy effected, when circumstances allow the installation of one, can best

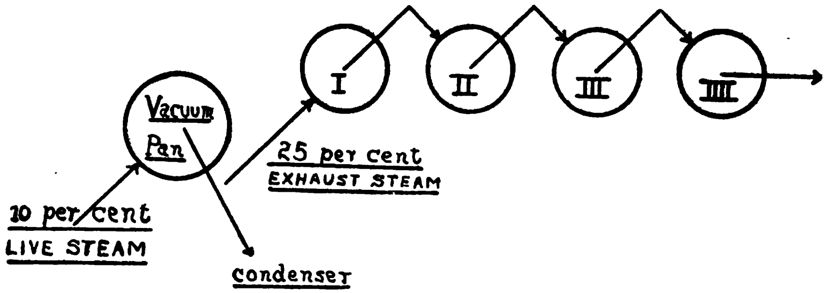


FIG. 12.

be shown as in Figs. 12 and 13, assuming 10 per cent. of steam be needed in a vacuum pan.

The question of the colour of the sugar will also decide the need or otherwise of a pre-evaporator. If faultless white sugar is wanted, any chance of getting coloured crystals by too high a temperature should be avoided. But the experiments of HAZEWINKEL[*] and NOËL DEERR[†] show that no great harm is done, especially if the juice passes very quickly through the apparatus.

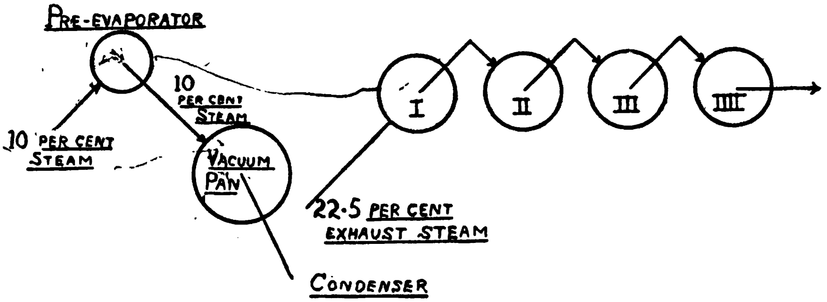


FIG. 13.

---

[*] *International Sugar Journal*, 1911, 212, 282. [†] *Ibid*, 1911, 341.

CHAPTER V.

Multiple Effect Evaporating Apparatus.

In the course of years evaporating apparatus have remained practically the same; we still maintain the original idea of RILLIEUX to evaporate two, three, four, or five times the quantity of water with 1 unit of steam. This is accomplished by means of an air-pump and condenser, either separate or combined.

Whether vertical or horizontal, climbing film or low juice column apparatus, we must bear at least two things in mind, when discussing evaporators, *i.e.*, their economy and their capacity. When we want to design a new apparatus or control an existing one, these two data should be ascertained first of all and be kept in view. Both are necessary of course, but they have little to do with one another. A plant which uses 1 part by weight of steam to evaporate 4 parts of water (Fig. 14) certainly works economically. Perhaps it evaporates only 3 parts of water, but also warms juice (Fig. 15). In this case, the combination must be balanced against the first system, and still greater economy will be the result.

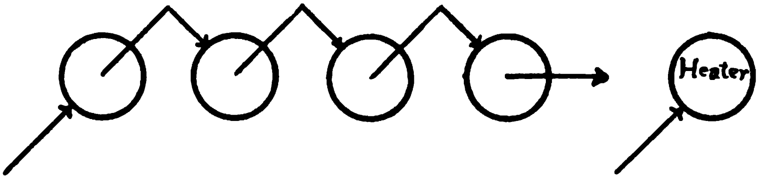


FIG. 14.

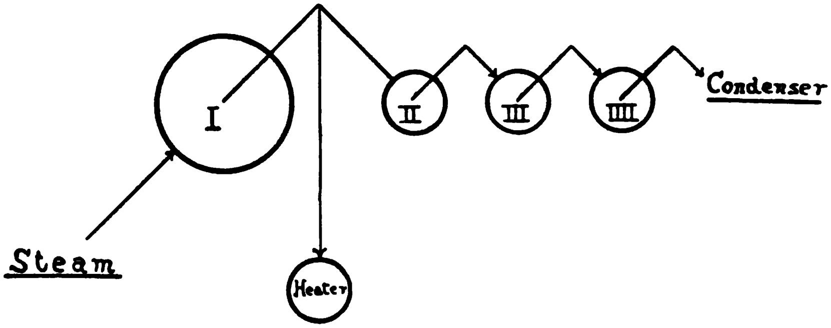


FIG. 15.

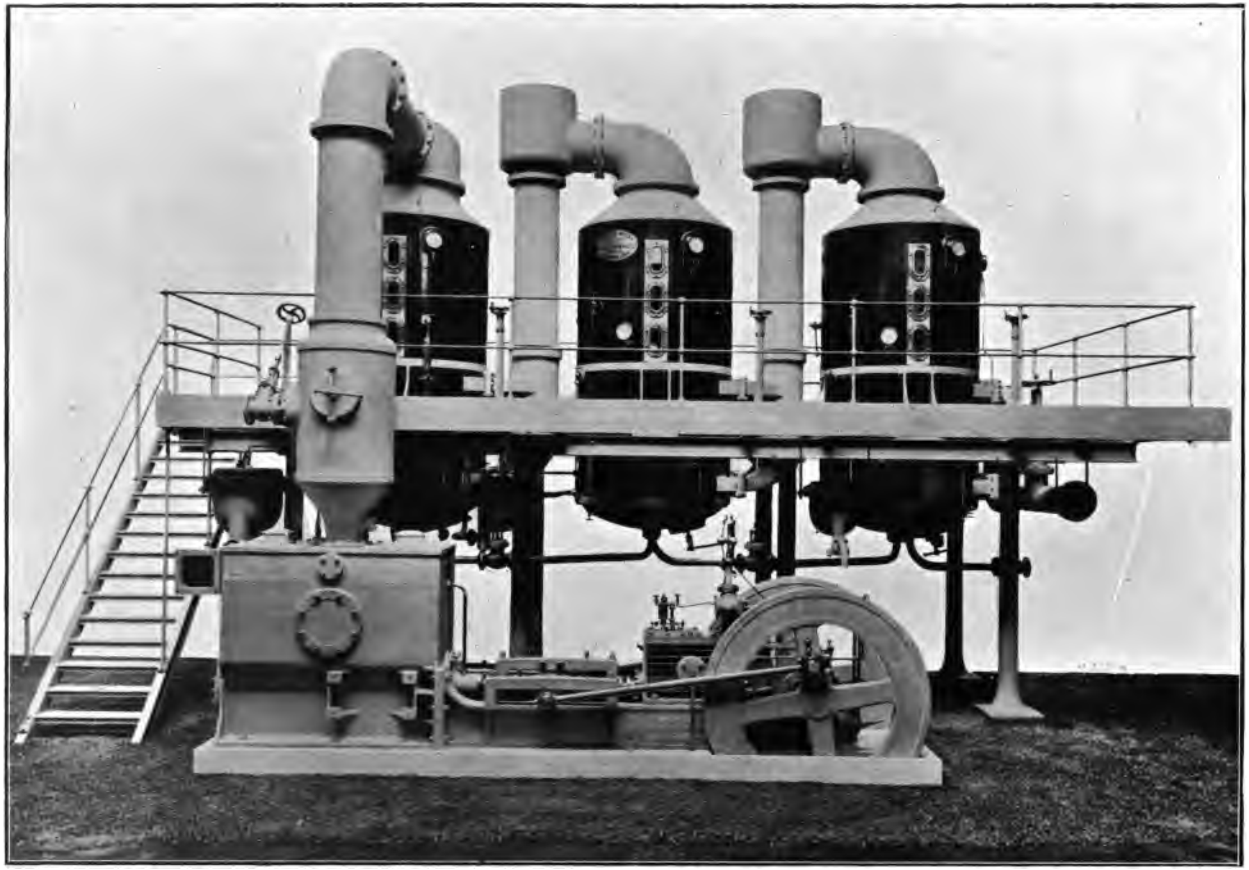


PLATE V.—HARVEY'S PATENT TRIPLE EFFECT.

Total heating surface, 2200 sq. ft. ; capable of concentrating 1760 imperial gallons of juice per hour from 8° to 28° Beaumé, with a steam pressure in the first calandria of from 1 to 3 lbs. per sq. in. A vacuum of about 27 in. of mercury is maintained in the third vessel, and the vacuum in the second and first vessels automatically adjusts itself, in the former case to about 15 in. and in the latter to about 3 in.

When the heat of the vapour from the last pan is used to heat juice, this represents another economy, as not only does it mean so many calories of heat saved, but it also implies less condensing water to be pumped up, and less air for the air-pump to draw. (See Fig. 10.)

Again, the introduction of the pre-evaporator means economy, as already explained. (See Figs. 12 and 13.)

Capacity, however, means simply how much water *in toto* can be evaporated. As will be remembered (see p. 26), the quantity of water evaporated per unit area becomes larger, the fewer vessels the set is composed of. This is primarily caused by the difference of temperature—the more pans compose the set, the smaller this difference will become. Thus, the more economically a set works, the smaller its capacity. The economy, however, cannot be developed indefinitely; the differences of temperature would become too small; and, besides, the loss of radiation would become unduly larger and the work for the air-pump get heavier, as all the pans represent so much more resistance to be overcome by the pumps.

In the case of the film evaporators, the capacity is larger per area of heating surface. Thus, in order to evaporate the same given quantity of water, a smaller heating surface will do the same work. This in turn will not only be useful in factories, where room is scarce (which is hardly much of an argument), but in large factories one climbing film set can take the place of two ordinary sets. This represents a saving in space, in attendance, and in loss by radiation.

The economy of steam in climbing film sets follows exactly the same laws as in the ordinary sets. In a quadruple climbing set, 1 kg. of steam evaporates 4 kg. of water.

The larger capacity per area of heating surface, however, will be found in the higher coefficient of transmission; more calories pass through the heating surface per 1° C. difference of temperature per unit area.

This evidently is caused by the greater velocity of the juice film allowing easy transmission of heat.

Regarding the caloric balance and the juice balance, losses may be met with in both—heat in the first, juice and sugar in the second.

If we make up the caloric balance of an ordinary quadruple effect (Fig. 16) without yielding extra juice vapour for heating purposes, this balance will appear as follows:

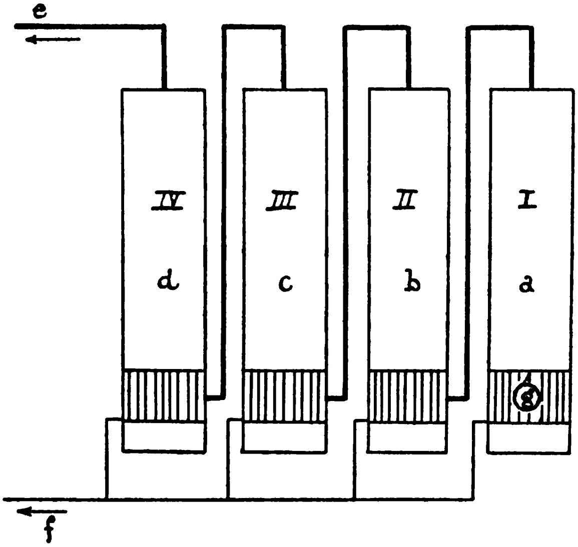


FIG. 16.

$$\underbrace{\text{Heat entering}}\quad = \quad \underbrace{\text{Heat leaving.}}$$

$$\left.\begin{array}{l}\text{Heat in entering steam}\\ \quad + \text{ heat in thin-juice}\end{array}\right\} = \left\{\begin{array}{l}\text{Heat in condensation water}\\ \text{Heat lost by radiation}\\ \text{Heat in juice vapour of last pan}\\ \text{Heat in ammonia tubes}\end{array}\right.$$

$$\underbrace{\text{Total heat}\left\{\begin{array}{ll}\text{125 kg. of thin-juice} & \text{at } 104^\circ \text{ C.}\\ \text{25 kg. of steam} & \text{at } 110^\circ\end{array}\right.}$$

$$\text{Total heat of}\left\{\begin{array}{lllll}\text{25 kg. of steam condensed in I at } 110^\circ & & & \\ \text{25 kg. of juice vapour condensed in} & & \text{II} & \text{at} & 104^\circ\\ \text{25 kg.} \quad ,, \quad ,, \quad ,, & ,, & \text{III} & ,, & 96^\circ\\ \text{25 kg.} \quad ,, \quad ,, \quad ,, & ,, & \text{IV} & ,, & 84^\circ\end{array}\right.$$

+ Total heat of 25 kg. of juice vapour from IV at 64°
+ ,, ,, 25 kg. of thick-juice at 64°

$$(125 \times 0{\cdot}9 \times 104) + [25 \times (606{\cdot}5 + 0{\cdot}305 \times 110)]$$
$$= (25 \times 110) + (25 \times 104) + (25 \times 96) + (25 \times 84)$$
$$+ 25 \times (606{\cdot}5 + 0{\cdot}305 \times 64) + (25 \times 0{\cdot}6 \times 64).$$

27,700 calories = 26,460 calories + losses by radiation and ammonia tubes.

The loss of heat may be calculated this way in actual practice and will prove rather small, if the ammonia tubes are not too large.

To deal with the theoretical design of a set, when a choice has been made of a particular system, and it has been decided how much water must be evaporated, and how much extra juice vapour must be furnished, one of the simplest methods, as proposed and used by BRUNINGS, may quite conveniently be selected. This consists in making heat equations for each body of the calories yielded, the calories needed, and so forth.

However simplified BRUNINGS' method is, it cannot be applied without making use of standards obtained in practice. This holds good also for the older methods such as JELINEK'S and HORSIN DÉON'S. But these latter assumed still other data, which subsequently did not prove to be quite accurate. It will be well therefore to recapitulate some facts and standards, as proved in practice, in carefully handled and well controlled factories.

(1) The air pump, in drawing away the gases developed, causes a vacuum; it is this vacuum with its accompanying low boiling point, which makes it possible to spread the range in temperature, between the initial steam and the boiling juice, over more than one stage.

(2) The different individual ranges of temperature in each body, together constituting the total difference, are not equally divided:—

(*a*) The higher the temperature of the steam, the smaller this difference will be.

(*b*) The higher the Brix of the juice, the larger the difference.

(*c*) The better the conductivity of the metal, the smaller the difference.

(*d*) The quicker the juice flows, the smaller again the difference.

(3) In a normal set, where the ammonia tubes do not exert an unduly great influence, each body in the set contrives to evaporate equal quantities of water per unit of heating surface and unit of time.

(4) The coefficients of transmission are not equal in the separate bodies; the smaller the differences in temperature, the larger this factor. These points are all connected one with another.

That the last body is capable of evaporating as much water per unit of heating surface as the first body may be explained as follows:—

The slower heat transmission is counterbalanced in various directions:—

(*a*) The latent heat of 1 kg. of steam at 60° is more than the latent heat of 1 kg. of steam at 104°.

Steam of 110° has a latent heat of 529 calories.
„ 104° „ „ 534 „
„ 96° „ „ 539 „
„ 84° „ „ 548 „
„ 64° „ „ 562 „

(*b*) As the vapour of 84° occupies more space* than the steam at 110°, owing to the lower pressure, the speed will be much higher. This steam meets a quantity of fluid, already concentrated, much smaller than the quantity of thin-juice.

(*c*) The juice entering the next pan under lower pressure will itself evaporate part of the water, independent of heat.

The differences in temperature† and the coefficients of transmission‡ which form the basis of calculations for designs are the results of actual factory practice, taken from evaporators which gave satisfactory results, while observing every precaution to ensure the normal working of all the bodies of the apparatus.

Double effect evaporators, as being obsolete, we will leave out of our consideration; for triple, quadruple, and quintuple effects, some figures that have been recorded are set forth on the next page.

---

* 1 kg. of steam of 110° C. occupies a space of 1·207 cub. metres.
1 kg. „ 85° C. „ „ 2·827 „ „

† *i.e.*, temperature of steam in steam-drum *minus* temperature of boiling juice.

‡ *i.e.*, calories transmitted through the heating surface per 1° C. difference of temperature, per 1 sq. metre in 1 minute.

Triple Effect.

Coefficients of Transmission.

	By Jelinek.	By Claassen.
I	37	40–50
II	25	30–35
III	14	15–20

Differences of Temperature.

I	5·5
II	7·5
III	24·0

Quadruple Effect.

Coefficients of Transmission.

	By Jelinek.	By Claassen.	By Brunings.	By Koppeschaar.
I	28	45	34	38
II	26	30	29	28
III	20	20	24	19
IV	5–6	12	10	11·5

Differences of Temperature.

	By Claassen.	By Brunings.	By Koppeschaar.
I	8	7	6
II	9	8	8
III	10	10	12
IV	17	24	20

Quintuple Effect.

By Curin.

	Coefficients of Transmission.	*Differences of Temperature.*
I	39·1	6·5
II	23·3	6·0
III	10·0	12·0
IV	8·3	14·0
V	6·4	15·0

In giving these standards one will notice immediately that the respective values are not alike. They prove that even well conducted evaporators allow a certain range of latitude and elasticity.

Selecting the quadruple effect as the most suitable one, combining economy with easy control and handling, we might for the purpose of design take the following standards :—

Coefficients of Transmission.		*Differences of Temperature.**	
I	35	I	7
II	27	II	9
III	20	III	12
IV	11	IV	22

In addition to these, we may assume 50 to be a standard coefficient for Pauly, and 80 for Kestner pre-evaporators.

With the aid of these data, the heating surface of any evaporating apparatus may be calculated. As an example, let us take an evaporator of the following specification:—

Capacity, 1200 metric tons of beets per 24 hours. Water to be evaporated, 100 per cent. Exhaust steam available, 30 per cent. The evaporators must supply extra steam to:—

(*a*) Vacuum pans (first product).

(*b*) Raw-juice heaters.

(*c*) Diffusion battery.

(*d*) Re-heaters for the thin-juice previous to entering the first body.

(*e*) Steam to re-heat thick-juice from 60 to 85° C.

The exhaust steam would be enough to evaporate the 100 per cent. of water in a plain quadruple effect. In that case, the heat of the vapour from the fourth pan only would be available to heat part of the raw juice.

---

*If we take the pressures from CLAASSEN's table, the differences, *i.e.*, pressure in steam-drum *minus* pressure in juice space, will be fairly equally divided:—

	°C			mm. mercury.
Steam in I	112	=	Pressure	1150
Juice in I	105	=	Pressure	910
Difference	*7*		Difference	*240*
Steam in II	105	=	Pressure	910
Juice in II	96	=	Pressure	660
Difference	*9*		Difference	*250*
Steam in III	96	=	Pressure	660
Juice in III	84	=	Pressure	420
Difference	*12*		Difference	*240*
Steam in IV	84	=	Pressure	420
Juice in IV	62	=	Pressure	165
Difference	*22*		Difference	*255*

To draw extra steam, however, from the apparatus, for all the various purposes enumerated above, would be impossible; thus we must either in addition supply live steam to the first body and make its surface correspondingly larger, or we must provide a pre-evaporator in order to leave less water for the exhaust steam to evaporate, and thus obtain the benefit of the live steam at double effect.

Selecting the last as the more profitable method, the amounts of extra steam, which must be supplied by the evaporators, have next to be calculated.

(A) *Steam needed in first-product vacuum pans.*[*]

Water to be evaporated, 8·5 per cent.; steam needed from PAULY, say 9 per cent.

Live steam needed in Pauly, 9 per cent.; water to be evaporated in quadruple effect: $100-9 = 91$ per cent.

(B) *Steam needed for heating raw juice.*

The heat of the vapour from the last body will be yielded partly to the raw juice if a superior system of heaters be used. A rise in temperature from 20° to 50° C. by means of vapour at 62° is possible in clean heaters having a coefficient of 5 to 6. 112 per cent. of raw juice heated from 20° to 50° will require $112 \times 0{\cdot}9 \times 30 = 3024$ calories.

Vapour of 62° will yield on condensation: $607-0{\cdot}7 \times 62 = 564$ calories.

Vapour required from fourth body: $\frac{3024}{564} = 5$ per cent.

To heat the juice to the required temperature of say 80°, $112 \times 0{\cdot}9 \times 30 = 3024$ calories will again be needed.

Taking vapour from the second pan at 96°, $\frac{3024}{607 - 0{\cdot}7 \times 90}$ calories will be required = 5·5 per cent., or say 6 per cent.

---

[*] Vacuum pans for after-products are better supplied with live steam, as they only boil strikes alternately, say once in two days.

(c) *Steam needed for diffusion battery.*

Entering Battery	Calories.	Leaving Battery.	Calories.
100 kg. slices at 10° =	1000	100 kg. pulp at 20 =	2000
212 kg. water „ „ =	2120	112 kg. juice „ „ =	2240
Total	3120	100 kg. water „ „ =	2000
		Total	6240
			3120
		Added in Battery..	3120

Steam of the first body at 105° will yield 607–0·7 × 105, and the quantity required will be $\frac{3120}{534} = 6$ per cent.

(D) *Steam to reheat thin-juice from 85° to 100°.*

The quantity of thin-juice is 124 per cent.;

The quantity of steam required from the first body will be:

$$\frac{124 \times (100 - 85)}{607 - (0{\cdot}7 \times 105)} = 3{\cdot}5 \text{ per cent.}$$

(E) *Steam to reheat thick-juice from 60° to 85°.*

The quantity of thick-juice is 25 per cent.

The quantity of steam required from the first body will be:

$$\frac{25 \times 0{\cdot}6 \times (85 - 60)}{607 - (0{\cdot}7 \times 105)} = 0{\cdot}7 \text{ per cent., say 1 per cent.}$$

Recapitulating, we have:—

	Receives steam of	Yields steam of	Extra steam furnished, besides that going to the next body.
PAULY	120 ..	116 ..	9 per cent. steam to vacuum pans.
First body ..	112 ..	105 ..	6 „ „ „ diffusion battery.
			3·5 „ „ „ reheating thin-juice.
			1·0 „ „ „ reheating thick-juice.
Second body..	105 ..	96 ..	6 „ „ „ heating raw juice.
Third body ..	96 ..	84 ..	
Fourth body..	84 ..	62 ..	5 „ „ „ heating raw juice.

Or expressing this graphically :—

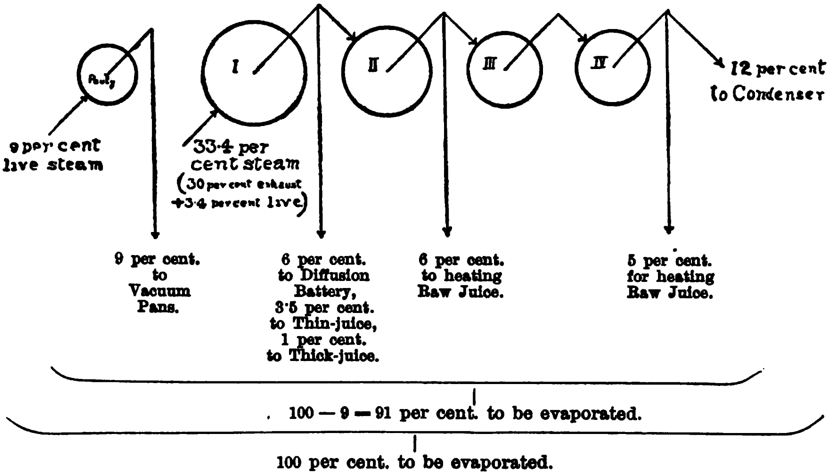

Pauly
I
II
III
IV
9 per cent live steam
33·4 per cent steam (30 per cent exhaust +3·4 per cent live)
12 per cent to Condenser
9 per cent. to Vacuum Pans.
6 per cent. to Diffusion Battery, 3·5 per cent. to Thin-juice, 1 per cent. to Thick-juice.
6 per cent. to heating Raw Juice.
5 per cent. for heating Raw Juice.
100 — 9 = 91 per cent. to be evaporated.
100 per cent. to be evaporated.

FIG. 17.

$$
\begin{array}{rl}
\text{If} \quad \text{I evaporates} & x \\
\text{II evaporates} & x - 6 - 3{\cdot}5 - 1 \\
\text{III evaporates} & x - 6 - 3{\cdot}5 - 1 - 6 \\
\text{IV evaporates} & x - 6 - 3{\cdot}5 - 1 - 6 \\
\hline
\text{Condenser absorbs} & x - 6 - 3{\cdot}5 - 1 - 6 - 5 \\
& 4x - 43{\cdot}5 = 91 \text{ per cent.} \\
& x = \dfrac{134{\cdot}5}{4} = 33{\cdot}6
\end{array}
$$

Thus, if only 30 per cent. of exhaust is available, 12·4 per cent. of additional live steam must be supplied to the first body and Pauly (9 per cent. to Pauly and 3·4 per cent. to first body).

The quantities to be evaporated are as follows :—

Pauly	evaporates	9	per cent.	at	116°	by means of	steam at	120°
I Body	,,	34	,,	,,	105°	,,	,,	112°
II ,,	,,	23	,,	,,	96°	,,	,,	105°
III ,,	,,	17	,,	,,	84°	,,	,,	96°
IV ,,	,,	17	,,	,,	62°	,,	,,	84°
Condenser absorbs		12	,,	,, at	62°	,,	water of	15°

The heating surfaces will be found by dividing the calories needed to evaporate these quantities by the coefficient of transmission multiplied by the difference in temperature, or :—

$$\frac{\text{Calories transmitted}}{\text{Coefficient of transmission} \times \text{difference in temperature.}}$$

The calories transmitted are calculated as follows:—

Pauly .. $9 \times (606{\cdot}5 + 0{\cdot}305 \times 116 - 100) = 9 \times 542 = 4878$
I body .. $34 \times (606{\cdot}5 + 0{\cdot}305 \times 105 - 116) = 34 \times 522 = 17748$
II ,, .. $23 \times (606{\cdot}5 + 0{\cdot}305 \times 96 - 105) = 23 \times 530 = 12190$
III ,, .. $17 \times (606{\cdot}5 + 0{\cdot}305 \times 84 - 96) = 17 \times 536 = 9112$
IV ,, .. $17 \times (606{\cdot}5 + 0{\cdot}305 \times 62 - 84) = 17 \times 541 = 9197$

The capacity per minute is $\frac{1{,}200{,}000}{60 \times 24} = 833$ kg. of beets.

The heating surfaces accordingly will be:—

Pauly $\frac{8{\cdot}33 \times 4878}{50 \times 4} = 203$ sq. metres, say 200 sq. metres.
I body $\frac{8{\cdot}33 \times 17748}{35 \times 7} = 604$,, ,, 600 ,,
II ,, $\frac{8{\cdot}33 \times 12190}{27 \times 9} = 418$,, ,, 420 ,,
III ,, $\frac{8{\cdot}33 \times 9112}{20 \times 12} = 316$,, ,, 320 ,,
IV ,, $\frac{8{\cdot}33 \times 9197}{11 \times 22} = 317$,, ,, 320 ,,
Total .. .. 1860 ,,

If the Pauly be replaced by a Kestner, the heating surface of the Kestner will be as follows: $\frac{8{\cdot}33 \times 4878}{80 \times 3} = 170$ sq. metres.

In cane factories, the heating surfaces may be calculated in a similar way,* but the initial quantities of exhaust steam available, water to be evaporated and extra steam required for heating purposes, are different. Moreover, the methods of manufacture vary considerably.

The quantity of water to be evaporated is the smallest in defecation factories, being about 67·5 per cent.

---

* This method, as described for the beet factory, is meant to serve only as a basis, variable according to the mutual relations between available exhaust steam, water to be evaporated, and various stations requiring steam for heating or boiling purposes.

If 30 per cent. of exhaust steam is available, this steam will be enough to evaporate in quadruple effect, while extra vapour is supplied to vacuum pans and juice heaters.

	Per cent.
Quantity of thin-juice	90
Brix of thin-juice	15
Brix of thick-juice	60
Quantity of thick-juice	22·5
Water to be evaporated	67·5
Brix of first massecuite	96
Quantity of first massecuite	14
Water to be evaporated in vacuum pan	8·5

If extra vapour be supplied to heat the raw juice and boil the thick-juice into muscovado, the following quantities will be needed:—

To heat 90 per cent. juice from 20° to 50° .. $90 \times 0{\cdot}9 \times 30 = 2430$
" " " 50° to 95° .. $90 \times 0{\cdot}9 \times 45 = 3645$

The first, by steam of 62°, will need $\frac{2430}{607 - 0{\cdot}7 \times 62} = 4{\cdot}3$ per cent., to be furnished by the last body.

The second, by steam of 105°, will need $\frac{3645}{607 - 0{\cdot}7 \times 105} = 6{\cdot}8$ per cent.

We then have:—

Evaporated in first body	x
" " second "	$x - 8{\cdot}5 - 6{\cdot}8$
" " third "	$x - 8{\cdot}5 - 6{\cdot}8$
" " fourth "	$x - 8{\cdot}5 - 6{\cdot}8$

$$4x - 45{\cdot}9 = 67{\cdot}5$$
$$4x = 113{\cdot}4$$
$$x = 28{\cdot}3$$

If 29 per cent. is available, no live steam will be needed. In cane factories, where the quantity of water to be evaporated is greater, suitable arrangements can be made to use the steam as economically as possible. The heating surfaces are calculated similarly to those for the beet sugar factory:—

	Per cent.
Evaporated in first body	28·3
" " second "	13·0
" " third "	13·0
" " fourth "	13·0
Absorbed by condenser	8·7

Calories transmitted:

First body .. $28{\cdot}3 \times (606{\cdot}5 + 0{\cdot}305 \times 105 - 80) = 15791$
Second „ .. $13 \times (606{\cdot}5 + 0{\cdot}305 \times 96 - 105) = 6890$
Third „ .. $13 \times (606{\cdot}5 + 0{\cdot}305 \times 84 - 96) = 6968$
Fourth „ .. $13 \times (606{\cdot}5 + 0{\cdot}305 \times 62 - 84) = 7033$

If the same capacity of cane be taken, viz., 833 kg. per minute, the heating surfaces will be:

First body .. $\frac{8{\cdot}33 \times 15791}{35 \times 7} = 536$ sq. metres, say 540 sq. metres.
Second „ .. $\frac{8{\cdot}33 \times 6890}{27 \times 9} = 236$ „ „ 240 „
Third „ .. $\frac{8{\cdot}33 \times 6968}{20 \times 12} = 241$ „ „ 240 „
Fourth „ .. $\frac{8{\cdot}33 \times 7033}{11 \times 22} = 242$ „ „ 240 „
Total .. 1260

or graphically as in Fig. 18.

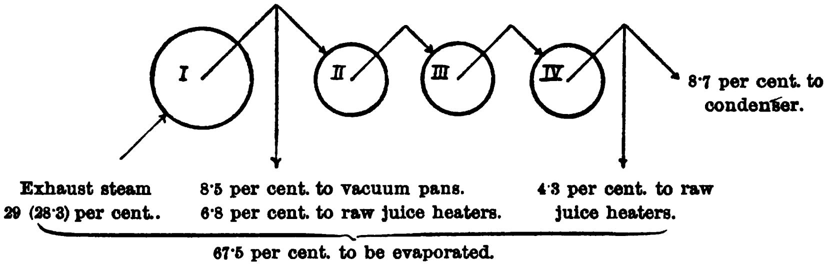

I
II
III
IV
8·7 per cent. to condenser.
Exhaust steam 29 (28·3) per cent..
8·5 per cent. to vacuum pans.
6·8 per cent. to raw juice heaters.
4·3 per cent. to raw juice heaters.
67·5 per cent. to be evaporated.

Fig. 18.

The heating surfaces of a complete Kestner quadruple set would be considerably smaller, but so far any series of coefficients of transmission have not been published.

CHAPTER VI.

Fundamental Parts and Accessories of Evaporating Apparatus.

Up to now the task of evaporating the enormous quantities of water in the sugar industry has been left as a rule to normal evaporating apparatus, these being a series of pans in which the juice boils at increasingly reduced pressures. Lately, however, pre-evaporators have been added in many factories, one or two working under pressure.

In future this combination will most probably take the place of the ordinary type, but whether or not this may be, different series of evaporator bodies will always have corresponding fundamental elements. In the present chapter these elements will be discussed and described.

In every type of evaporation apparatus we find:

(1) Vessels containing a space in which the juice boils, and a space in which the steam yields its heat.

(2) The apparatus which creates a vacuum, the pump, and the condenser, either separate or combined.

To these must also be added the heaters which receive steam from the pans and thus act as surface condensers.

The vessels or bodies are built either vertically or horizontally. As already mentioned, the latter type was Rillieux's original design, while vertical types were first constructed by Robert. Both are met with at present in sugar factories, and it may be taken for granted that their efficiency is equal, *i.e.*, in an apparatus of either type the same quantity of water may be evaporated per unit of surface per hour. Of course it is assumed that nothing prevents the free action of the heating surface.

In every pan of whatever type, we find a space to contain the juice, and another to receive the steam or the juice vapour. In horizontal apparatus* the juice space is intersected by a series of tubes, slightly inclined, which tubes connect two chambers at either end that are filled with steam (Fig. 19).

---

* *See* also **Noël Deerr's "Cane Sugar," Figs. 163 and 164.**

In vertical apparatus the steam-drum is entirely built within the pan; two wrought-iron tube plates are united by a series of vertical tubes, which latter form a communication between the space below and that above the steam-drum. The juice in this case is inside the tubes, and the steam outside them (Fig. 20).

In horizontal pans the case is exactly the opposite; outside the tubes the juice is boiling, inside the tubes the steam enters and the condensation water flows off.

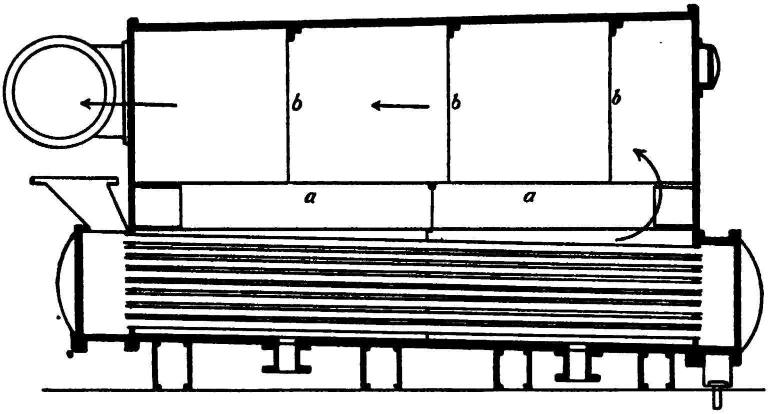


FIG. 19.

a a and b b, Baffle plates.

The two plates which unite the tubes must be composed of a metal that allows a certain amount of elasticity. In horizontal bodies this is still more necessary than in vertical ones because of the great length of the tubes.

In the vertical ones, however, wrought-iron is also necessary because the tubes are expanded tightly in the holes of the tube plate. In the horizontal pans the tubes are fastened by means of iron rings and bolts and nuts, and are made gland tight by means of rubber packing. Both types, it may be repeated, work well, as will be shown in a subsequent chapter dealing with researches in heat transmission. Still there is some difference to be noted. The horizontal pan must be filled with juice above the tubes, as otherwise part of the heating surface will be inoperative; and the tubes must be fixed slantwise in order that the condensed water can be removed quickly. Juice catchers must necessarily be added.

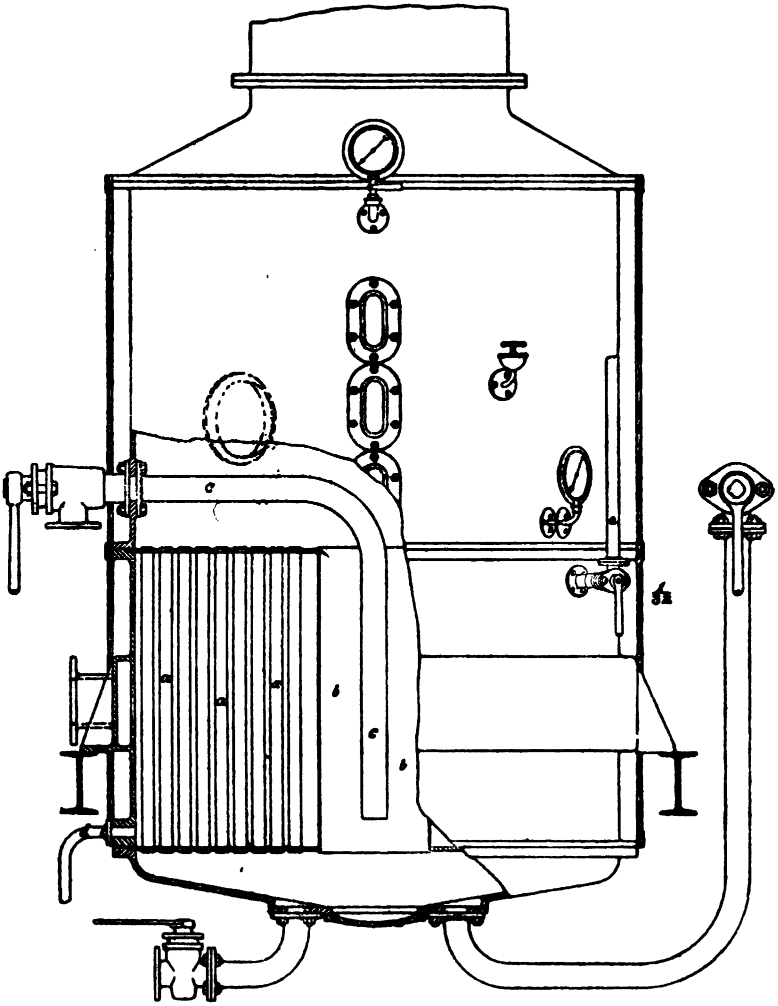


FIG. 20.

a a, Juice tubes. *b*, Central circulating tube. *c*, Juice intake pipe.
d, Pipe to draw off condensed water. *e*, Pipe to draw off incondensible gases.

The vertical pan needs only a small volume of juice*; on a small scale the climbing film principle will cause a high transmission. The condensed liquid will flow off easily, and if the pan be constructed of sufficient height, for instance if 15 feet of space be added above the steam-drum, no juice catcher will be needed.

The material from which the tubes are constructed must combine strength with good heat transmission. Hitherto brass has been largely used on account of its great capacity for transferring heat. Seamless steel tubes are, however, rapidly replacing the brass ones, as they are much cheaper and are but little inferior in their efficiency. They are not attacked so easily by ammonia gas as are brass tubes. Their diameter† must allow for mechanical cleaning, as scraping must always follow the boiling out with soda and acid. (See page 89.)

In horizontal pans where the scale from the juice will accumulate outside the tubes, the diameter of the latter can be kept smaller. The usual length is 3 to 6 feet in ordinary vertical pans; in Kestner pans 18 to 24 feet, and in horizontal pans 12 to 15 feet.

In vertical pans so-called "circulation tubes" of a much larger diameter are often inserted. Whether these really favour circulation is doubtful. At all events reliable comparative tests are lacking.

As may be readily concluded from what has been said about heat transmission in the Second Chapter, the steam-drum in vertical pans and the steam spaces with series of tubes in the horizontals must be relieved of water and gas as completely and quickly as these are formed. Any stagnation of water or accumulation of gas will seriously hinder the transmission of heat, a fact easily understood, and yet often overlooked.

A glass gauge always in view must be provided, as this will reveal any water which accumulates.

Different methods are followed to relieve the steam-drums of this condensed liquid; they should be mentioned, as they have often considerable influence on the efficiency of the pans. In beet factories about the same quantity of condensed liquid will be available as the water which is evaporated, *i.e.*, about 100 per cent. The first pan will yield condensed water from exhaust and live steam, which gain balances the loss caused by the vapours from the last pan, which are partly absorbed by juice heaters and partly by the condenser.

---

* Which means quicker circulation, especially preferable in cane juices and granulated factories.

† 40 to 50 mm. (1·5 to 2 inches) is usually chosen.

As a modern beet factory uses from 60 to 70 per cent. of steam, some choice can be made here. Only the hottest water in addition to the condensed liquid from the vacuum pans will be fed to the boilers, leaving the rest to be used for sweetening-off in the filter-presses, washing filter-cloths, and other uses.

In cane factories less water must be evaporated, viz., 60 to 70 per cent., while more steam is needed, *i.e.*, 80 to 90 per cent. All the available condensed water, in addition to that of the vacuum pans, should be saved and returned to the boilers. In this way the heat of the condensed water is used to the best advantage.

The scheme which is sometimes proposed of returning the condensed water into the steam-drums of the next pan cannot be recommended; in theory the reduced pressure will affect steam formation, but in practice the entering water will hamper the transmission of heat.

Various methods are followed to relieve the steam-drums of their condensed water; the following points may be stated.

The pressure in the steam-drums is highest of course in pre-evaporators and first pans, a tendency prevailing to use higher pressure in these latter. The higher the pressure of the initial steam, the greater the difference of temperature, which again can be divided over a larger series of pans than can a smaller one. If a pre-evaporator is used, the steam-drum receives only live steam, and the pressure in it is always higher than 1 atmosphere (14·7 lbs.). In first pans this is also the case, while in the second pans either a slight pressure above or beneath 1 atmosphere will be formed. In the steam-drums of the third and fourth pans, we find the vacuum present in the juice space of the second and third pans; while the steam-space of the heaters which are linked in between the last pan and the condenser will have the vacuum obtained in the last pan.

Those steam-drums where a vacuum prevails can be relieved of their condensed water by a barometric tube of a length proportionate to the vacuum. This barometric condenser has the advantage of being simple and reliable. (See diagram of quadruple effect, Plate VI).

The condensed water when under slight pressure is often removed by a syphon, in which a column of water offers enough resistance to prevent any loss of steam.

Steam traps are used to relieve the steam-drums of first pans and pre-evaporators of their condensed water. Automatic contrivances acting in the same manner, as the old montejus, are doing good service. By their aid it is possible to feed water of about 106° to 108° C. into the boilers. When feed pumps are used, the limit is 98° to 99° C., if good care is taken that the pumps do not suck, but that the water flows towards the pump.

When automatic condensed water returners are used, a gauge glass within easy reach must be provided. The mechanism is simple and reliable.

The pressure of the exhaust steam varies from 20 lbs. to nearly 30 lbs. per sq. inch, corresponding to temperatures of 112° to 119° C.

In pre-evaporators, especially KESTNER's, steam of far higher temperature, namely up to 150° C., is used. Automatic returners will be especially useful in this case.

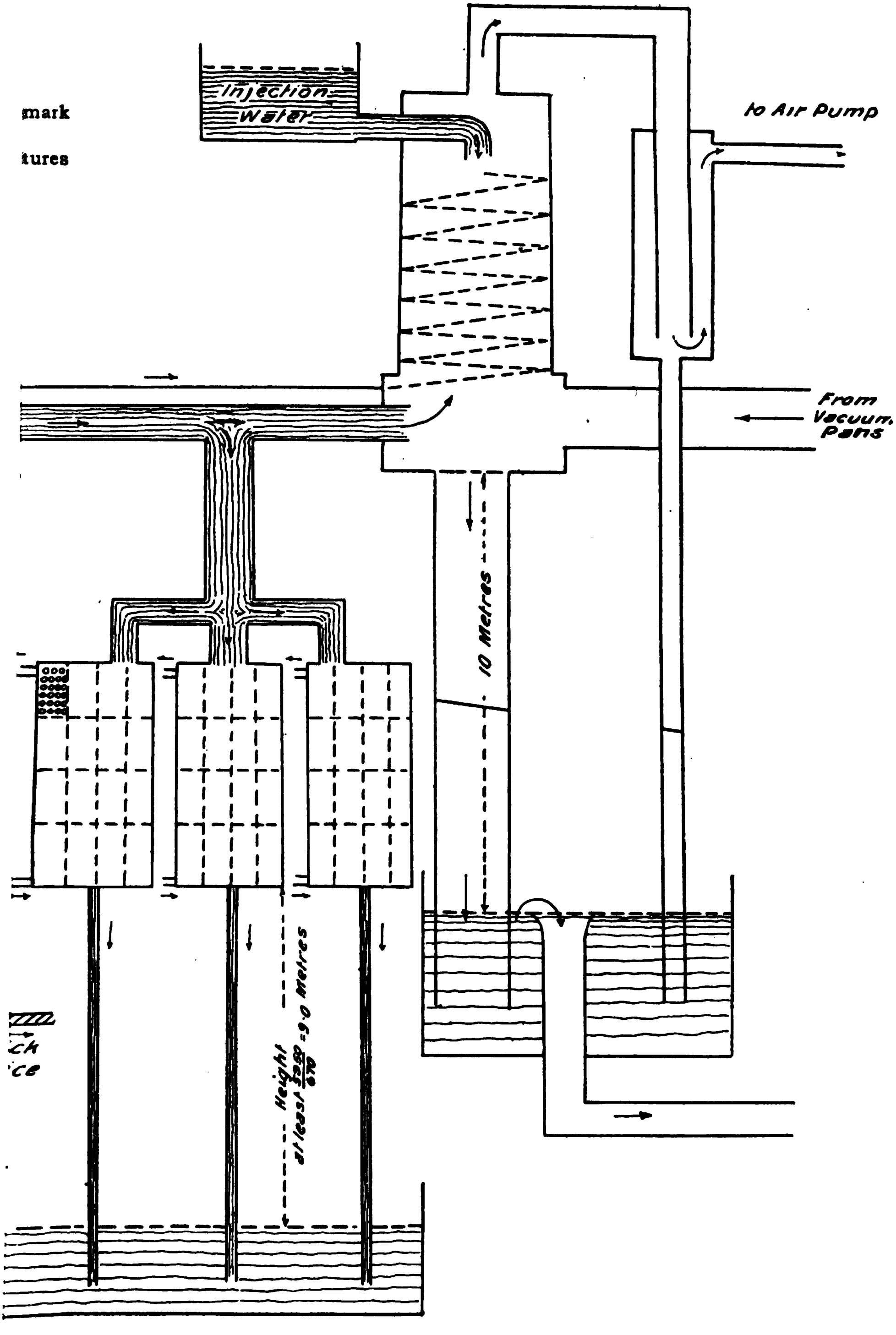
If live steam is supplied as well, a manometer must be provided on the steam-drum which will enable the man-in-charge to note how much pressure is attained in it.

Of the juice space formed by the actual body of the pan, the following may be said. In the lower part a gauge glass must be provided, within easy reach and sight. A low juice column is a *sine quâ non* to obtain the highest possible result. The climbing film idea of the Kestner pan can be copied on a small scale in ordinary pans. The gauge glass must therefore be placed low, and have only sufficient length to allow a low juice level. In ordinary pans glasses are provided, though they are not absolutely necessary if a well-constructed gauge glass is provided.

As there is a chance that the juice vapours may carry along particles of juice, which would be a loss when they reached the next steam-drum, juice catchers or entrainers are provided in the pans or in the vapour tubes.

The greatest speed of the juice vapour is reached in the last pan, a speed far greater than that in the first one. Juice vapour in the last mark

tures



Injection Water
to Air Pump
From Vacuum Pans
10 Metres
Height at least 5950/670 = 9.0 Metres
ck
ce

pan at 65° C. will occupy a space of 6·2 cubic metres per kg., while steam at 108°, which we usually find in the first pan, will occupy a space of 1·4 cubic metres per kg. Thus the speed of the vapour is greatest in the last pan, and therefore the chance of loss by entrainment largest. If the juice space above the steam-drum be sufficiently high, *i.e.*, not less than 15 feet, no special device to catch juice particles is needed, at least not in the first three bodies.

Of the various designs of juice catchers, the shields, built inside, are the simplest. They do not reduce the velocity as do HODECK's, nor can juice remain in them and become a source of inversion.

The method by which the juice pipes are arranged, whether the inlet is at the bottom or above the steam drum, is not of any importance; it is inside the tubes that the transmission takes place.

In horizontal pans the steam space and juice space are arranged somewhat differently, but this does not make any substantial difference having regard to what has already been said in enunciation of the various laws.

In vertical pans the condensed water which forms on the outside of the tubes will flow to the lowest part of the steam-drum. If proper care be taken to remove the water, there is no chance whatever of the water hindering the transmission of heat; and for this reason a vertical position of the tubes is preferable to a horizontal one. The replacing of tubes can be done during the campaign,* as can cleaning either by boiling out or by scraping.

In horizontal pans the tubes serve also to conduct off the condensed water, for which reason they are constructed with a slant. After the campaign they are taken out and cleaned. The outside, it should be remembered, will be encrusted with scale, the reverse of the vertical tubes. An advantage of this type is the cleaning of the inside, identical with the outside of horizontal ones. In the first body the exhaust steam deposits oil layers; suitable oil-catchers will catch most of this, but if they are lacking, a viscous layer is formed which will retard the transmission of heat.

---

* But the inter-campaign overhaul should be so thorough that this is really never needed.

Prinsen Geerligs gives analyses of such incrustations :—

	A.	B.	C.
Machine oil	28·4	28·5	13·9
Iron oxide	39·4	58·8	82·6
Copper „	30 0	2 5	—
Lead „	1·0	6·2	2·3
Graphite	1·2	4·0	1·2

Benzene* is frequently used to remove this scale; if intelligently applied and used with care, the inside of vertical steam-drums can be successfully cleaned. In horizontal ones, of course, the inside can be scraped or brushed. In vertical ones the steam-drum is partly filled with water, and on top of the water some 15 gallons of benzene are poured. This benzene is allowed to soak into the inside of the steam-drum surface very slowly, the contents at the bottom being drawn off very gradually.

As to the length of the tubes, various sizes are to be met with. In ordinary vertical pans, rather long tubes, say 6 to 10 feet, will make it possible, more or less, to utilize the Kestner principle; the juice level is kept low, the tubes being occupied mostly by a film. In the real Kestner pans 18 to 22 feet is the length of the tubes. In horizontal pans the length is 12 to 15 feet depending on the size of the bodies.

THE APPARATUS, THE RÔLE OF WHICH IS TO CONDENSE THE VAPOUR THAT IS CONTINUALLY PRODUCED.

Each steam-drum serves as condenser for the steam from the previous body or for live steam. But the extra steam drawn, which serves for heating in special heaters, and also the vapour from the last body which heats in combination with another source, is condensed in these heaters, and these actually form part of the installation.

Besides the economy effected, when extra steam is supplied by a body, this seems to stimulate evaporation, doubtless through the rapid condensation, and if well designed and of correct proportion it will serve to ensure the bodies evaporating a maximum quantity of water per unit of heating surface.

The heaters which receive vapour from the last body will moreover relieve the central condenser.

---

* *International Sugar Journal*, 1911, p. 672.

The type of heater required to heat raw juice, thin-juice, etc., has been gradually improved. Its efficiency depends on:

(1) The speed of the liquid which must absorb the heat;
(2) The temperature of the steam;
(3) The design of the heater in regard to the withdrawal of air from the steam and froth from the juice;
(4) The cleanness of the tubes.

The first mentioned, the speed, has been gradually increased. In the old heaters the juice changed its direction three times; this was increased to six times, then twelve times, until at present heaters are built with a sixteen to eighteen-fold circulation.

Obviously the juice goes through the heater in the same interval of time as before, but in that period more steam has occasion to come in contact with the juice than previously, because the juice is forced to pass over a much longer surface in the same time, *i.e.*, its velocity is greater. Juice which has taken up heat is rapidly replaced by colder juice, thus favouring transmission of heat.

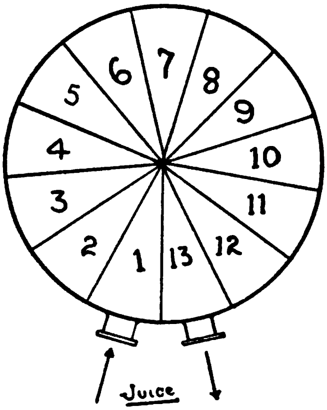


FIG. 21.

Few comparative trials have been made on the transmission of heat for sugar juices, but so far as the author's own experience goes, the following approximate values may be accepted. Two distinct designs must be mentioned, *i.e.*, horizontal and vertical heaters.

In the vertical heaters the circulating system is divided into six, twelve, sixteen or eighteen compartments. The juice goes zig-zag, up and down; the steam enters above while the water is drawn off at the bottom. The steam-chest must be provided with proper ammonia tubes, and the juice space must have an outlet for air and froth (Fig. 21).

In these the transmission coefficient is low compared with the horizontal designs. The latter have 8, 12, 16, or 20 compartments of equal size with horizontal tubes. The juice enters at the bottom and gradually zigzags first horizontally and then vertically, driving the air forward. The steam is forced to yield its heat in compartments as well. The water is drawn off at the bottom, as are the air and ammonia from the steam or vapour. (Figs. 22 and 23.)

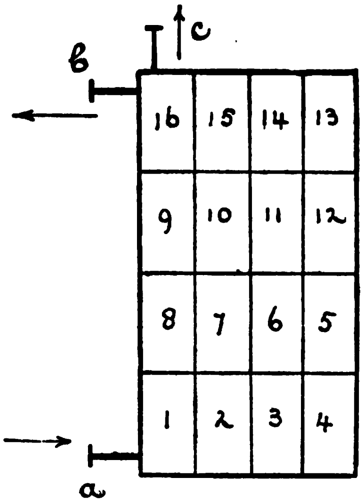


FIG. 22.
HORIZONTAL HEATER, FRONT JUICE COMPARTMENTS.
(*a*) Cold juice inlet.
(*b*) Warm juice outlet.
(*c*) Scum outlet.

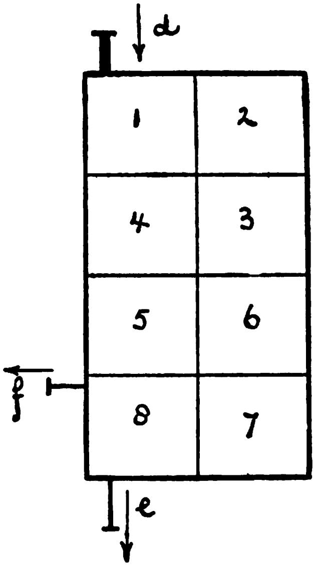


FIG. 23.
HORIZONTAL HEATER, FRONT STEAM COMPARTMENTS.
(*d*) Steam inlet.
(*e*) Condensed water outlet.
(*f*) Air and ammonia gas outlet.

The lowest transmission will be found in double open heaters, of which the highest coefficient may be taken as 1.

In regard to the better types of heaters, the following is taken from the author's practice :—

	Circulation.	Temperature of Steam.	Heating Surface. Sq. m.	Temperature of Juice, °C. in.	out.	Coefficient of Transmission.
(*a*) Vertical ..	6 ..	100 ..	300 ..	55 ..	80 ..	$\frac{25 \times 830}{300 \times (100-67)} = 2\cdot0$
(*b*) Horizontal..	8 ..	65 ..	300 ..	25 ..	55 ..	$\frac{30 \times 830}{300 \times (65-40)} = 3\cdot3$
(*c*) Vertical ..	16 ..	70 ..	160 ..	20 ..	60 ..	$\frac{40 \times 622}{160 \times (70-40)} = 5\cdot2$
(*d*) Horizontal..	16 ..	100 ..	80 ..	60 ..	85 ..	$\frac{25 \times 622}{80 \times (100-72)} = 6\cdot9$

In the last type the transmission was highest, and for such designs a coefficient of 7* will not be too high. The influence of the cleanness of the tubes is very great. The quicker, however, the juice is driven through, the less incrustation will be deposited. Still, it is a good practice to group so many heaters that any one of them may be cut out and cleaned.

As to the differences in temperature, the following series are interesting, but no conclusion can be drawn from them. The total length of tubes is divided into five imaginary groups:—

a	67	75	83	91	100	steam
Juice ..	55	61	67	73	80	
	12	14	16	18	20	
b	40	46	52	58	65	steam
Juice ..	25	32	39	46	55	
	15	14	13	12	10	
c	40	47	54	61	70	steam
Juice ..	20	30	40	50	60	
	20	17	14	11	10	
d	72	79	86	93	100	steam
Juice ..	60	66	72	78	85	
	12	13	14	15	15	

The resistance in heaters with a 16-fold circulation will be greater than in those with slower circulation; still observations show that the pressure does not surpass 1·5 atmospheres (22 lbs.), as long as the tubes are clean.

---

* Textbooks usually give 10, which is probably excessive.

The diameter of the tubes is from 30 to 40 mm. ($1\frac{1}{4}$ to $1\frac{1}{2}$ inches). The material is either brass or steel.

Thermometers should be provided at both entrance and exit of the juice. As they must be cleaned during the campaign, suitable covers must be provided.

The rest of the vapour of the last body, with whatever air and incondensible gases have finally gathered, is condensed and absorbed by cold water, leaving only the smallest quantity, which can neither be condensed nor absorbed, to be removed by the air-pump. Only in the case where the air-pump is at the same time the condenser must the injection water also be removed by the pump.

The quantity of water which must condense and absorb the steam is larger in practice than we can calculate by theory. But the calculated quantity may serve as a minimum for comparison.

1 kg. of steam from the last body of say 62° C. will possess a total heat of $606{\cdot}5 + 0{\cdot}305 \times 62 = 625$ calories.

After transferring the latent heat, $607 - 0{\cdot}708 \times 62 = 563$ calories, to the cold injection water, there will be left 1 kg. of water of 62° C., which will mix with the injection water. If we use water of say 15° C., the ideal situation will be reached if it absorbs the visible heat of the condensed steam entirely and flows off at 62° C.; $62 - 15 = 47$ calories, per kg. vapour $\frac{563}{47} = 12{\cdot}0$ kg. injection water is needed. The quantity which is actually used can be calculated if the temperatures of injection water and fall water are known. Besides these temperatures, the quantity of steam which is absorbed from evaporators and vacuum pans must be known fairly accurately. An equation can be made of caloric values: if, for instance, the temperature of the fall water be 40° C., and the temperature of the injection water 15° C., this equation will be 15 + injection water + steam × $(606{\cdot}5 + 0{\cdot}305 \times 62)^1 = 40 \times$ (injection water + steam). Injection water = 23 × steam.*

The nearer the temperature of the fall water coincides with the condensed vapour, the less water is used in the condenser. The design of the central condenser therefore must be such that the greatest quantity of steam comes in contact with as small as possible a quantity of water. Various designs are doing good service, one of the best being SCHWAGER's "Cataract" condenser. The water flows over a spiral series of steps, the vapour enters at the bottom and meets a surface of water evidently as large as it can be made. A safety contrivance, as indicated in the diagram shown in Plate VI, serves to catch any water which might be drawn over by the air-pump. If this addition is lacking, the air-pump runs a great chance of being damaged, as several accidents in sugar factories have proved.

---

* The water pump must be of a capacity to furnish 30 to 35 kg. of water per kg. steam.

The air-pump employed to remove the air and incondensible gases has been improved lately, especially in regard to the valves. The flat Hoerbiger steel valves are rapidly taking the place of the spiral spring type. They are not so liable to breakage and will not get incrusted with oil hardened by the high temperature sometimes occurring in the cylinder.* As to the size of the air-pump, the design is more or less empirical. JELINEK† calculates 0·25 to 0·30 cub. metres per kg. vapour condensed, which corresponds fairly with actual installations the author has worked with. Calculations regarding the quantities of air removed cannot be accurate, unless they represent actual tests. These quantities must fluctuate if we remember that cane juices yield less incondensible gas than beet juices, and cold water may liberate more air than warm water.

The contents of so-called "wet" air-pumps will always be larger on account of the water itself, which must be removed as well. If water is scarce, cooling towers are resorted to, which cool the fall water as much as possible. Surface condensers of different designs also give satisfaction.

In a previous chapter we pointed out the loss of heat by radiation (see p. 54). That a good method of isolating bodies and tubes will be economical need not be emphasized. In tropical countries the bodies are usually encased in wood. A better practice would be to jacket them with the best kieselguhr or infusorial earth, because the latter isolates heat well and withstands high temperatures. Silk and felt have higher isolating values, but they are more expensive and cannot withstand high temperatures.

---

* In any case the cylinder of the air-pump should be provided with a jacket wherein cooling water circulates.

† *Suiker-Techniek* 1907-8, p. 87.

In addition to isolation, the vapour tubes should not have too great a diameter, and juice-catchers or entrainers outside the bodies should be avoided. With their large surface they will cause a loss by radiation, and instead of catching juice they will condense steam. In many factories the lowest part of the bodies, containing the juice, remains unprotected. That this is a mistake hardly needs to be pointed out.

The central condenser is best constructed as high as possible, above the roof in fact, thus taking advantage of the open air to favour condensation, while simultaneously saving space inside the factory.

A special apparatus, designed to test non-conducting materials, consisting of a cast-iron tube 16 feet long, should be used to test the various brands of infusorial earth on the market. Into this tube, which is covered by the material to be examined, steam is introduced and the condensed water weighed. The different results obtained by covering the tube with different materials will reveal their respective non-conducting values.

To give any definite factor for the loss caused by radiation is not practicable, the factors which influence it always varying. Dr. Claassen* has measured the loss in a quadruple effect with juice-heater attached, and cites 149·4 kg. per hour, working one million kg. of roots per 24 hours, and using a heating surface of 1450 sq. metres.

---

* *International Sugar Journal*, 1911, p. 97.

CHAPTER VII.

The Control of the Evaporating Apparatus.

Of the various stations together composing the complicated sugar manufacturing plant, the evaporation stage is often neglected as far as any attempt to control its efficiency and economy is concerned.

With the increasing use of extra steam for heating purposes, the importance of systematic control becomes apparent. The author is convinced that often those who are charged with the care of the factory would be entirely at a loss for an answer if they were asked as to either the efficiency or the economy of their apparatus. If comparisons are made with other factories as to fuel—coal or bagasse—or the Brix which has been attained, they would be fair only if for both the exact capacity per unit surface were given.

To devote a separate chapter to the question of control is therefore fully justified.

Before an apparatus is certified fit to commence evaporation work, the steam drums should be tested by means of hydraulic pressure. Any leaking tubes can then be removed in time and replaced by new ones. After each campaign a few tubes will have to be exchanged, being either pierced by tiny holes made by ammonia gas or having become thin by scraping. In the vapour tubes and juice spaces leaks may be expected. The best method to detect and remedy these is to exhaust the air within by means of the air-pump. Instead of juice, the bodies are filled with water, and the various valves are closed. Serious leaks can be heard, while smaller ones will be revealed by the aid of a lighted candle.

Next to be examined are the traps for the condensed water and other devices which serve to relieve the steam-drums of all the water that is condensed in them.

When setting the apparatus in motion with juice, it is a good practice to warm the bodies first, at least the first one, especially in horizontal evaporators[*] where the greater length of the tubes must cause a certain tension in the tube-plates. In Kestner apparatus this will doubtless be equally necessary.

When evaporation is going on, the control is usually extended to:—

(1) The Brix of the thick-juice;
(2) The sugar content of the condensed water;
(3) And the loss of sugar by decomposition.

The Brix is tested in the laboratory, making use of average samples from 12 hours' work. Automatic Brix spindling devices are in use in beet factories, giving satisfactory results.[†]

The sugar content of the condensed water is tested regularly, either by Fehling's solution or by α-naphthol. The first is the most reliable one, even if it takes more time to carry out.

As already remarked, if sufficient room is provided, no juice will be entrained at all. In horizontal bodies, however, this is not practicable; they are necessarily built rather low, and juice-catchers must be provided for them. Apart from the loss of sugar, which must be prevented in any case, the sugar contained in condensed water is apt to do harm if it reaches the boilers. The high temperature prevailing there will decompose the sugar and convert it into acids, which will corrode the boiler plates.

Various experimenters have measured the quantity of sugar lost by entrainment. Thus E. W. KERR[‡] in a study on this subject argues that in a quadruple effect the tendency to entrain will be less than in a triple or double effect, on account of the slower speed of the vapour in the last body.

The loss of sugar by decomposition may be determined thus: In samples of the thin and the thick-juice, the sucrose and the chlorine, or the sucrose and the ash, are determined, and the results before and after evaporation compared. To determine the chlorine, BRUNINGS[§] chooses the Volhardt method, which is as follows:—

---

[*] The author remembers a case he witnessed of a horizontal body where, through lack of this precaution, the front plate developed a crack, causing a serious delay.

[†] In cane factories perhaps these are not to be recommended, as the inside of the apparatus is liable to become a source of infection.

[‡] *International Sugar Journal*, 1911, p. 673.

[§] *Suikerindustrie*, 1904, p. 243.

To, say, 25 c.c. of the juice are added 10 c.c. of a standard solution of silver nitrate and a few drops of nitric acid. Then ferrous sulphate is added. The silver nitrate left in excess is titrated back by a standard equivalent solution of ammonium thiocyanate, thus:—

$$AgNO_3 + NH_4CNS = AgCNS + NH_4NO_3.$$

The titre of the $AgNO_3$ is 1 c.c. = 0·001 grm. Cl. Accurate results may thus be obtained.

As remarked in Chapter I, the decomposition does not only depend on the high temperature but also on the length of time during which the juice is exposed to this temperature. Thus Kestner evaporation must on account of its great speed offer less danger even with high temperatures than ordinary sets.

In ordinary apparatus, a low juice level will favour speed; and as it also favours evaporation, high levels should not be allowed.

As to the efficiency and economy of the apparatus, we must ascertain the quantity of water evaporated per sq. metre and per hour, and also the quantity of steam which is introduced into the first body. If extra steam is supplied by the bodies to juice-heaters, the efficiency of each body must be ascertained.

The most reliable method would be to measure the quantity of condensed water yielded by each body, but as this is impossible practically, we must follow the method detailed below.

As the reading of the Brix spindle represents a basis on which to calculate the quantities of water that have been evaporated, the Brix is determined in average samples of the juices leaving each body. The sampling only offers some difficulty for those bodies which stand under vacuum. For these, sample bottles must be provided with a well-fitting rubber stopper, connected by vacuum tube with the cock which taps the sample.

If the weight of thin-juice per hour = Q
The Brix thin-juice entering first body = B
,, ,, juice from the ,, ,, = B_1 of heating surface *a*
,, ,, ,, ,, ,, second ,, = B_2 ,, ,, *b*
,, ,, ,, ,, ,, third ,, = B_3 ,, ,, *c*
,, ,, ,, ,, ,, fourth ,, = B_4 ,, ,, *d*

The quantity of water evaporated per hour and sq. metre will then be:

$$\text{In first body} \;..\; \frac{Q \times (B_1 - B)}{B_1 \times a}$$

$$\text{In second body} \;..\; \frac{Q \times B \times (B_2 - B_1)}{B_1 \times B_2 \times b}$$

$$\text{In third body} \;..\; \frac{Q \times B \times (B_3 - B_2)}{B_2 \times B_3 \times c}$$

$$\text{In fourth body} \;..\; \frac{Q \times B \times (B_4 - B_3)}{B_3 \times B_4 \times d}.$$

If the temperature and the manometer and vacuum gauge readings are recorded during the time that these samples are being taken, we should have the required data for calculating the efficiency as well as the economy of the complete apparatus.

The following is a sample taken from actual practice:—*

Amount of thin-juice per hour = 26534 kg.
Brix of the thin-juice = B = 11·75.
,, juice from the first body, B_1 = 14·73 *a*, 200 sq. metres.
,, ,, ,, second ,, B_2 = 19·65 *b*, 200 ,,
,, ,, ,, third ,, B_3 = 28·62 *c*, 200 ,,
,, ,, ,, fourth ,, B_4 = 62·67 *d*, 200 ,,
Evaporated in I per hour per sq. metre = 26·8 kg. water.
,, II ,, ,, = 26·5 ,,
,, III ,, ,, = 26·7 ,,
,, IV ,, ,, = 27·7 ,,
Temperature of steam in I .. .. = 110·5° C.
,, thin-juice .... = 87·4° C.
Boiling point of juice in I .. .. = 103·3° C.
,, ,, II .... = 95·2° C.
,, ,, III .. .. = 85·4° C.
,, ,, IV .... = 61·2° C.

Transmission:—

$$\text{In I} = \frac{26{\cdot}8}{60} \times \frac{606{\cdot}5 + 0{\cdot}305 \times 103{\cdot}3 - 87{\cdot}4}{110{\cdot}5 - 103{\cdot}3} = 34{\cdot}2.$$

$$\text{In II} = \frac{26{\cdot}5}{60} \times \frac{606{\cdot}5 + 0{\cdot}305 \times 95{\cdot}2 - 103{\cdot}3}{103{\cdot}3 - 95{\cdot}2} = 29{\cdot}0.$$

$$\text{In III} = \frac{26{\cdot}7}{60} \times \frac{606{\cdot}5 + 0{\cdot}305 \times 85{\cdot}4 - 95{\cdot}2}{95{\cdot}2 - 85{\cdot}4} = 24{\cdot}4.$$

$$\text{In IV} = \frac{27{\cdot}7}{60} \times \frac{606{\cdot}5 + 0{\cdot}305 \times 61{\cdot}2 - 85{\cdot}4}{85{\cdot}4 - 61{\cdot}2} = 10{\cdot}4.$$

---

* BRUNINGS' *Suikerindustrie*, 1904, p. 11.

Taking 125·0 per cent. of thin-juice on the weight of beet, the bodies have evaporated per weight of roots :—

	Per cent.
Body I	25·2
„ II	25·0
„ III	25·1
„ IV	26·1
Total	101·4

This was accomplished by 25·2 per cent. of steam, 1 kg. of steam evaporating 4 kg. water.

The economy and efficiency of the apparatus are normal for this type (representing the old method), without drawing extra steam for heating. That the last body evaporates more than any of the others may be caused by the accumulated effect of "self-evaporation."

In the following an example is given (from the author's practical tests) where extra steam was drawn from the first body. The last body evaporates more than the previous one, for the same reason, viz., the self-evaporation by the lower pressure :—

				Per cent. Roots.	Coefficient of Transmission.
First body	evaporated	20·4 kg.	per hour per sq. m.	= 28·6 ..	37·3
Second „	„	21·0 „	„ „	= 22·5 ..	21·0
Third „	„	20·05 „	„ „	= 21·5 ..	15·7
Fourth „	„	23·2 „	„ „	= 25·0 ..	12·3

28·6 — 22·5 = 6·1 per cent. was available for the heaters of the raw juice; 97·6 per cent. of water was evaporated in all. This was accomplished by 22·5 per cent. of steam at quadruple effect :—

$$1 \text{ per cent. of steam evaporated } \frac{97{\cdot}6 - 6{\cdot}1}{22{\cdot}5} = \frac{91{\cdot}5}{22{\cdot}5} = 4 \text{ per cent.}$$

6·1 per cent. of steam evaporated 6·1 per cent. of water at single effect in the first body, and besides heated raw juice in heaters. The saving may be calculated as follows :—

Without drawing extra steam from the first body, the use of steam would be $\frac{97{\cdot}6}{4} + 6{\cdot}1 = 30{\cdot}5$ per cent. of steam, whereas now the use of steam was 28·6; the saving being 30·5 — 28·6 = 1·9 per cent.

For quintuple evaporation the following items* may be noted:—

	Kg.	Per cent. Roots.	Coefficient of Transmission.
First body evaporated per hour per sq. m.	27·1	37·7	34·2
Second „ „ „ „	14·1	12·2	20·5
Third „ „ „ „	15·5	13·4	18·4
Fourth „ „ „ „	16·7	14·4	21·5
Fifth „ „ „ „	20·7	14·1	9·4
		91·8	

37·7 — 12·2 = 25·5 per cent. was available for heating raw juice and for vacuum pans. In all, 91·8 per cent. of water was evaporated.

91·8 — 25·5 = 66·3 per cent. of water was evaporated by 12·2 per cent. of steam at quintuple effect; 1 per cent. of steam evaporated $\frac{66·3}{12·2}$ = 5·4 per cent. of water.

25·5 per cent. of water was evaporated by 25·5 per cent. of steam at single effect in the first body, besides heating raw juice and vacuum pans.

The saving may be calculated as follows:—

Without drawing extra steam, the use of steam would be $\frac{91·8}{5}$ = 18·2 per cent. + 25·5 for heaters, and vacuum pans = 43·7 per cent., whereas now the use of steam is 37·7 per cent.

The saving was 43·7 — 37·7 = 6 per cent. on roots.

As already remarked, the quantities of water which are evaporated per sq. metre and per hour should be equal, whether extra steam for heating is drawn off or not. If unequal quantities are shown to be evaporated, apart from such small differences as may be accounted for by self-evaporation, it will be well worth while ascertaining the cause.

The ammonia tubes form a direct communication with the central condenser, and they afford the means for regulating the quantities referred to. By reducing or enlarging the diameter of the tube, less or more steam is drawn along with the incondensible gases. The difference in temperature can thus be influenced, as the pressure will be equally affected. Thus more water can be evaporated, but at the cost of more steam.

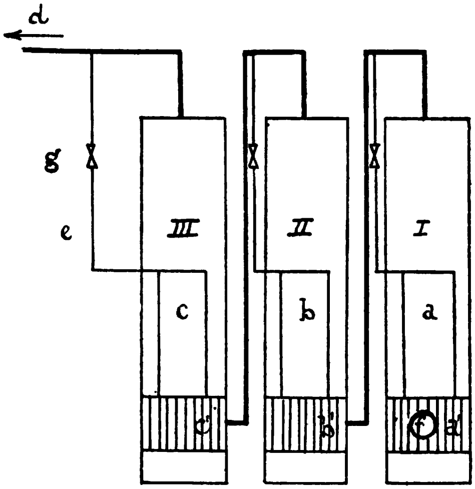
---

* *Technisch Tijdschrift*, 1905, p. 60.

Influence of Ammonia Tubes.—If *g*, the ammonia valve leading from *III* (in Fig. 24) is shut down, there is more pressure in *c′*; more pressure in *b*; less difference of temperature in *II*; less evaporation in *II*; less steam in *c′*; and less evaporation in *III*.

If *g* is opened wider, there is less pressure in *c′*; less pressure in *b*; greater difference of temperature in *II*; more evaporation in *II*; more steam in *c′*; and more evaporation in *III*.

If the ammonia valves from *III*, *II*, and *I* are wide open, steam drawn from the steam-drum in *I* will be drawn all through, the pressure will be kept up and more evaporation will be the result, at the expense of more steam than is strictly needed for triple evaporation.

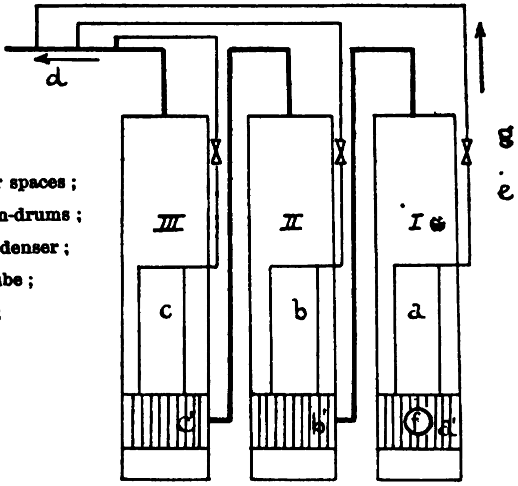


a, *b*, *c*, vapour spaces; *a′*, *b′*, *c′*, steam-drums; *d*, pipe to condenser; *e*, ammonia tube; *f*, steam-inlet; *g*, valve.

FIG. 24.

If the first body does not possess tubes, but simply cocks, this forcing is impossible.

If the ammonia tubes of each body are connected individually with the central condenser, all steam which is drawn away is lost (Fig. 25). The steam-drums will be liberated completely of their gases, but it is impossible to separate these from the accompanying steam. If this system is followed, the diameters should be the minimum, as already given. To supply large tubes and leave the regulating to the man-in-charge is not to be recommended.



a, b, c, vapour spaces;
a', b', c', steam-drums;
d, pipe to condenser;
e, ammonia tube;
f, steam-inlet;
g, valve.

FIG. 25.

In a study on this subject, CLAASSEN* calculated the losses of steam in the tubes; and taking the diameters, which are usually designed with 40 mm. as the basis, he found the following results:—

	Heating surface.	Evaporation per hour per sq. m.	Pressure in atmospheres.	Spec. vol. in cub. m. per kg.	In 1 second, kg.	In 1 hour, kg.	Per cent. on total steam.
First body..	350	43	1·75	1·0	0·31	1116	7·4
Second ,, ..	300	30	1·3	1·33	0·24	864	9·6
Third ,, ..	250	28	0·9	1·88	0·17	612	8·7
Fourth ,, ..	250	28	0·6	2·75	0·11	396	5·7

By choosing smaller diameters, this loss can be reduced to a minimum.† CLAASSEN's own practical experience taught that the following diameters were sufficient:—

First body	10 mm.	$\left(\frac{13}{32}\text{ in.}\right)$
Second ,, ...	15–20 mm.	$\left(\frac{19}{32}-\frac{25}{32}\text{ in.}\right)$
Third ,, ...	20–25 mm.	$\left(\frac{25}{32}-1\text{ in.}\right)$
Fourth ,, ...	30 mm.	$\left(1\frac{3}{16}\text{ in.}\right)$

Evidently the diameter gradually increases as the gases keep on accumulating.

---

* *International Sugar Journal,* 1912, p. 396.

† See previous Chapter.

If the control, as outlined in this Chapter, reveal abnormally low coefficients of transmission, corresponding with a low capacity of evaporation per sq. m., the various causes that give rise to it and their remedies may include: (1) If either condensed water or incondensible gas is not drawn off as quickly and completely as it should be, the transmission drops. The remedy is evident; and in regard to the first, the simplest and most reliable means of drawing off the water should be chosen. (2) If the tubes become incrusted, the heating capacity drops quickly, and only an increased supply of steam can keep up a sufficiently high Brix of the thick-juice.

Cleaning as thoroughly as possible should not be delayed, as the growing scale will soon offer difficulties to the process of scraping and brushing.

The author* tried to throw some light on the question whether systematic control would reveal a regular increase in the use of steam. Here the caloric value (pressure) of the steam must be taken into account.

Steam entering first body per cent. on roots.	Coefficient of transmission in first body.	Steam entering first body per cent. on roots.	Coefficient of transmission in first body.
29·6	37·2	28·9	23·4
29·6	41·0	35·4	31·6
32·0	37·0	32·6	27·2
33·1	40·0	34·4	28·6
36·0	33·4	36·9	25·2
30·7	21·6	38·4	28·7

The transmission in the first body becomes smaller towards the end of the campaign, and the evaporation of the required quantity of water is kept up by increased steam pressure. In regard to the quantity of scale deposited, the soap test will give a rough estimate.

	Calcium oxide in thin-juice per cent. by volume.	Calcium oxide in thick-juice, per cent. by weight.
Average	0·0054 ..	0·0126
Specific gravity	1·005 ..	—
Per cent. by weight	0·0051 ..	—
Sugar	12·5 ..	57·0
CaO per unit of Sugar ..	0·0004 ..	0·00022
Remaining in evaporators		0·00018

---

* *International Sugar Journal,* 1911, p. 149.

The following quantities of scale were weighed in a beet factory:—*

Kg. of beets worked.	1st body.	2nd body.	3rd body.	4th body.	Total.
66 million	—	—	—	—	86
62 ,,	122	19	18·5	42·5	202
57 ,,	89·7	20	23·2	44·0	176·9
78 ,,	30·0	22	32·5	168·5	253
78 ,,	48·5	27·5	43·0	195·0	314

For each factory, those conditions should be studied which lead to as little deposit as possible.

The cleaning is done by boiling out the tubes; in beet factories carbonate of soda, followed by hydrochloric acid, is used.

The carbonate of soda changes the compounds of lime and organic acids into carbonates, which in turn are more easily attacked by the hydrochloric acid. Reliable factory experiments show that the action of these chemicals is of great value.

The boiling with soda solution (Na_2CO_3) of 1 to 1½ per cent. strength, as long as possible and as hot as possible, followed by boiling with hydrochloric acid of 1 per cent. for a couple of hours, considerably lightens the task of the men who have to scrape out the scale. The hydrochloric acid used for this purpose is impure ("muriatic acid"), and contains 30 to 35 per cent. of pure HCl.

In cane factories, as recommended by PRINSEN GEERLIGS,† caustic soda ($NaOH$) is mostly used under atmospheric pressure for six hours.

Some interesting investigations have also been carried out by S. S. PECK of Honolulu, who found:—

Original total residue	1·93	=100
Dissolved by water	0·68	= 35·2 per cent.
,, hydrochloric acid	1·23	= 63·7 ,,
,, sulphuric acid	0·92	= 47·7 ,,
,, sodium carbonate	0·39	= 20·2 ,,
,, sodium hydroxide	0·90	= 48·6 ,,
,, sodium carbonate and hydrochloric acid	1·44	= 74·6 ,,
,, sodium carbonate and sulphuric acid	1·09	= 56·5 ,,
,, sodium hydroxide and hydrochloric acid	1·32	= 68·4 ,,
,, sodium hydroxide and sulphuric acid	1·22	= 63·2 ,,

---

* Heating surface of the evaporation plant was 1950 sq. metres.

† "Cane Sugar and its Manufacture," p. 209.

Molasses has been tried with good results for cleaning the inside of the steam drums; benzene, too, has been used.

With regard to the analyses of incrustations, it may be said that these are not constant, neither in beet nor in cane factories. **Prinsen Geerligs**[*] gives several analyses of incrustations from factories with different methods of working. A characteristic difference of defecation *versus* carbonatation is that in factories using the first method, the first and second bodies incrustate sooner than those of a carbonatation factory, because the filtering is better in the later case. Phosphoric acid predominates in the first bodies. In carbonatation factories silica, lime, and oxalic acid predominate in the last bodies. **Thurlow**[†] in a special study on the cleaning of tubes in evaporators recommends boiling in the open or under pressure, not under vacuum; he has obtained good results by using caustic soda (NaOH) first and acid afterwards. Evidently the nature of the incrustation will make some difference, but in cane factories scraping or brushing also must finish the cleaning process. The scraping itself needs close supervision, both with regard to the men and to the tubes. For the first, wet sponges should be provided by which the mouth and nose can be protected. And the scraping must be done carefully, as otherwise the tubes are easily damaged.

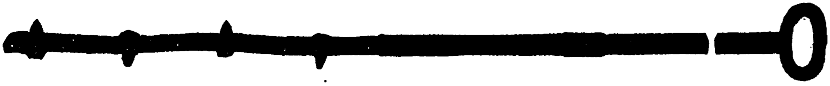


Fig. 26.

Fig. 27.

The scraper should be made to accurate gauge, fitting the diameter of the tube; the pattern indicated in Fig. 26 gives satisfactory results. For heaters, steel brushes (Fig. 27) are better adapted, especially if the heaters are cleaned regularly every two or three days.

If a heating surface is designed larger than the requirements demand, the transmission will show a lower coefficient. In this case improvement can be reached only by making the heating surface smaller. Sometimes the last bodies are designed with a larger heating surface; but then this only means a waste of material.

---

[*] "Cane Sugar and its Manufacture," p. 205.

[†] *International Sugar Journal*, 1911, p. 328.

If extra steam is drawn from a body whose heating surface is just as large as the body which follows next, this latter body will receive too little steam, and consequently cannot evaporate a normal quantity; the coefficient will in consequence be low.

In the following example, from the author's practice, extra steam was drawn from the first, second, and third bodies. The first body was larger than the second but the difference in surface was not utilized fully,* and thus its transmission was lower than normal.† The second body received this surplus of "excess steam" produced by the first, and its coefficient therefore was higher than normal. The second body furnished extra steam without being correspondingly larger. Thus the third had a shortage of steam and a low transmission. The fourth had a shortage of steam as well and showed a coefficient which was too low.

The quantities of water evaporated per cent. on the roots corresponded with these coefficients:—

	PAULY.	I.	II.	III.	IV.
Heating surface, sq. metres	250	500	230	230	230
		a			
Water evaporated, per cent. on roots	9·2	30·6	18·7	16·2	10·8
Coefficient of evaporation	38·0	26·3	49·0	6·3	8·8
		b			
Water evaporated, per cent. on roots	10·8	34·4	21·7	16·4	10·5
Coefficient of evaporation	41·1	23·8	44·1	6·0	10·3
		c			
Water evaporated, per cent. on roots	8·6	28·1	19·1	18·6	10·6
Coefficient of evaporation	35·0	28·0	25·0	7·5	9·1
		d			
Water evaporated, per cent. on roots	6·4	30·0	21·0	17·1	11·3
Coefficient of evaporation	15·1	29·0	33·2	6·7	8·3
Kg. water evaporated per sq. metre per hour.					
a	12·8	21·2	28·2	24·8	16·3
b	13·8	22·0	30·2	22·9	14·6
c	11·8	19·2	28·4	27·6	15·8
d	8·5	20·0	30·3	24·8	16·4

---

* That means, the quantity of extra steam which was drawn in was too small.

† This quadruple was completed by a Pauly, which however did not work as a real Pauly, but was fed by the first pan.

After what has been said about the mutual relations of bodies which furnish extra steam besides, the remedy is self-evident.

As to the figures for horizontal apparatus, the following results were calculated by the author* from data supplied to him relating to an American beet granulated factory :—

Beets worked : 1,016,000 kg. per 24 hours.
„ „ per minute : 705 kg.
Juice drawn off per 100 kg. of roots : 105 litres.
Brix of the diffusion juice : 13·5°.
„ milk-of-lime : 12·0°.
„ the thin-juice : 16·0° (mixed juice).
„ the thick-juice : 65·0°.
Heating surface of the first body : 501·6 sq. metres. Temperature 104°C.
„ „ „ second „ 501·6 „ „ 99°C.
„ „ „ third „ 501·6 „ „ 85°C.
„ „ „ fourth „ 501·6 „ „ 58°C.
Total .. .. .. 2006·4 sq. metres.

Weight of diffusion juice : 111 kg. per 100 kg. of roots.

Milk-of-lime at 12° Brix = about 7° Bé. = 65 grms. of lime per litre.

If the lime be 2·5 per cent. on the roots, 2500 grms. of CaO are added. This lime, contained in 40 litres of milk-of-lime, weighing 42 kg., dilutes the juice with 42—2·5 = 39·5 kg. of water. If 4 kg. remain in the lime-cake, and the sweetening-off water is equal to the water used to slake the lime, the quantity of thin-juice will be 111 × 35·5 = 146·5 kg. Leaving loss of sugar in the lime-cake out of consideration, the Brix of this thin-juice would reach

$$\frac{13{\cdot}5 \times 111}{146{\cdot}5} = 10{\cdot}2$$

If x is the sugar in the thin-juice, and the Brix of the mixed juice, which enters into the evaporation apparatus, is 16° Brix,

$$13{\cdot}5 \times x = \frac{16 \times (146{\cdot}5 + x)}{100}$$
$$x = 11{\cdot}8$$

The total quantities of mixed juice will be :

$$111 \times 35{\cdot}5 \times 11{\cdot}8 = 158{\cdot}3 \text{ kg.}$$

---

* *Suikerindustrie*, 1911, p. 402.

For concentration to 65° Brix, the weight of thick-juice:

$$\frac{16 \times 158{\cdot}3}{65} = 39 \text{ kg.}$$

Water to be evaporated $= 159{\cdot}3 - 39 = 119{\cdot}3$ kg. per cent. on the roots.

Then is evaporated per minute: $7{\cdot}05 \times 119{\cdot}3 = 841$ kg. water.

The first body will evaporate $\frac{841}{4} = 210$ kg. water per minute.

Steam required for this:

$$x \times (607 - 0{\cdot}7 \times 109) = 210 \times (606{\cdot}5 + 0{\cdot}305 \times 104 - 86)$$

$$x = \frac{115920}{531} = 218 \text{ kg. per minute.}$$

But 1 kg. of steam evaporates $\frac{841}{218} = 3{\cdot}85$ kg. water. Per hour per sq. metre, this is equal to $\frac{60 \times 841}{2006{\cdot}4} - 25$ kg. water.

The coefficients of transmission are:

$$\text{For first body } \frac{115920}{501{\cdot}6 \times (109 - 104)} = 46$$

$$\text{For second body } \frac{25}{60} \times \frac{606{\cdot}5 + 0{\cdot}305 \times 99 - 104}{104 - 99} = 44$$

$$\text{For third body } \frac{25}{60} \times \frac{606{\cdot}5 + 0{\cdot}305 \times 85 - 99}{99 - 85} = 16$$

$$\text{For fourth body } \frac{25}{60} \times \frac{606{\cdot}5 + 0{\cdot}305 \times 58 - 85}{85 - 58} = 8$$

The efficiency and economy is equal to that of a corresponding vertical apparatus. The coefficient of transmission in the second body is probably lower in reality. This may be attributed to an error in recording the temperature.

CHAPTER VIII.

Special Designs.

Competition has in the course of years retained only those patterns which have proved practical and efficient. The quantity of water which they evaporate per sq. metre has been brought to a maximum, the economy depending on the manner in which the bodies are linked together.

In details improvements have been made, and various engineering firms and individual engineers have given their names to these designs. Thus we find mentioned the names of Wellner-Jelinek, Yaryan, Schwager, Greiner, Claassen, Karlik, Lillie, Swenson, and many others.

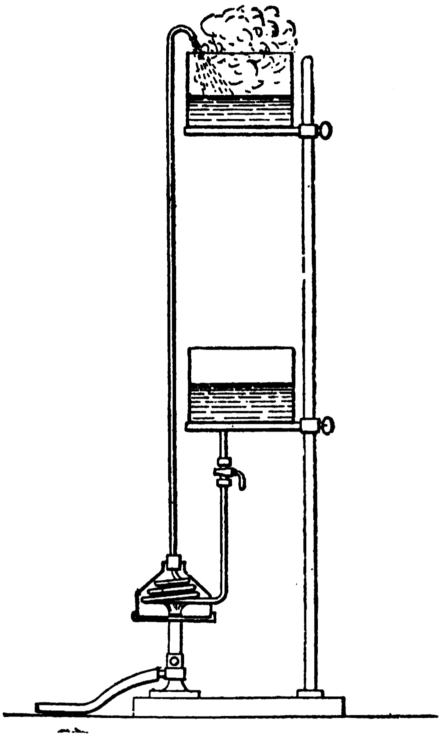


Fig. 28.

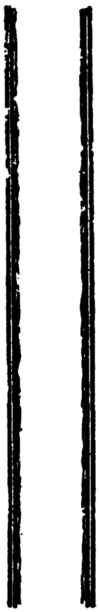


Fig. 29.

A really new feature in the development of evaporation is the climbing film principle, which has raised the quantity of water capable of being evaporated per sq. metre still higher. This brings with it the possibility of evaporating a certain quantity of water by means of a smaller heating surface than the ordinary sets allow. The inventor of this new system is the engineer Paul Kestner, who constructed his apparatus first for various chemical industries* before it was tried in sugar factories. Its rapid distribution justifies a more minute description and the recording of the results of some experiments with it.

In Fig. 28 an experiment† is graphically shown which closely represents what happens in the bodies on a larger scale. The steam which is developed in the longest tube rises, and the liquid climbs in thin layers up the wall of the tube (see Fig. 29), coming out at the top. The diameter of the tube is limited, as it is the velocity of the steam which forces up the film. In practice the longest tubes are 7 metres (23 ft.), having a diameter of 25 to 70 mm. (0·75 to 2·75 inches). If the reservoir containing the juice is placed 3 ft. above the commencement of the tubes, the concentrated liquid will be lifted 20 ft. high.

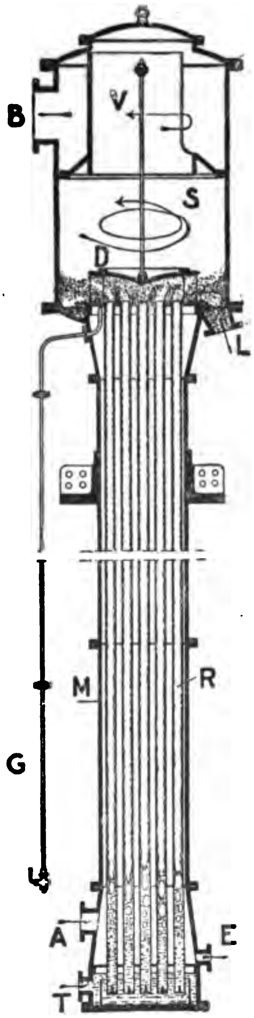


Fig. 30.

In Fig. 30, a Kestner body is represented. Its characteristics are, besides the long tubes, the small juice space which in turn causes a most rapid evaporation. This rapidly demonstrates the fact that higher temperatures, up to 130° C., do not attack the sugar solutions, and do not therefore cause a dark coloration. It also explains why so little incrustation is formed.

---

* In 1902 the Kestner firm sold 183 sq. metres of heating surface of Kestner evaporators, in 1910 this quantity rose to 18,848 sq. metres. In that year 975 apparatus were at work, distributed as follows: sugar industry, 376; alkali industry, 335; glue, 87; extracts, 46; nitrates of lime, 24; various 107.

† *International Sugar Journal*, 1912, p. 336.

A modification of the Kestner principle is represented in Fig. 31. Besides climbing up, the concentrated liquid is allowed to descend again, reaching the bottom still more concentrated. It is used to produce so-called "concrete" sugar, *i.e.*, solid thick-juice, which product finds a ready sale in some Asiatic countries where no high class article is demanded.

As to the capacity of Kestner evaporators, some tests have been taken, of which the following by SAILLARD* deserves mention.

In Noyelles-sur-Escaut (France) a common triple effect has a Kestner pre-evaporator. The capacity of the factory is 300 tons per 24 hours. The following items may be given:—

		Sq. metres.
Heating surface of Kestner	....	50·79†
,, ,, first body	..	205·0
,, ,, second ,,	....	137·0
,, ,, third ,,	..	171·0
Total	.. .. ..	563·0

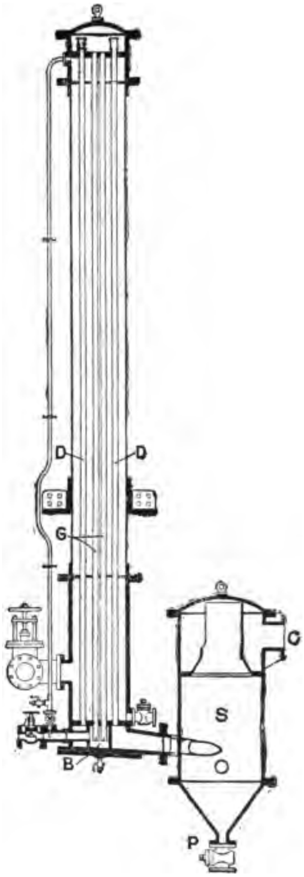


FIG. 31.

Tubes of Kestner: 77 of 7 m. length, thickness 2 mm., outside circumference 34 mm. This Kestner was guaranteed to evaporate 4000 kg. (80 kg. per sq. metre) if fed with steam of 1·5 atm. (126° C.)

---

* *Technisch Tijdschrift*, 1909-10, p. 230.

† *i.e.*, measured inside, the outside is also given as 57·5 sq. metres.

The following were the results of a test conducted by **Saillard** :

Duration of Test.	2 hours.	69 minutes.	1⅜ hours.	Average.
Water evaporated per hour	4837	4641	4306	4594
,, ,, per hour per sq. metre	96	92	84	90
Temperature of juice entering	99·9	101·6	101·2	100·9
,, juice going out.. ..	104·2	105·9	104·8	104·9
Difference of temperature	15·6	15·71	13·94	15·08
Coefficient of transmission	55	52·6	54·8	54

The transmission of heat is the same as has been observed in Pauly pre-evaporators.

As to coloration, **Saillard** compared the Kestner with a Pauly :

	Kestner at Noyelles.		Pauly.	
	Before.	After.	Before.	After.
True purity..	94·11	94·07	94	93·98
Ash coefficient	38·02	38·0	37·71	37·7
Alkalinity	0·022	0·028	0·028	0·0141
Sugar	100	100	100	100
Reducing sugars..	0	0	0	0
Colour	100	103	100	101

In economy, the Kestner bodies follow the same rules which have been laid down in previous chapters.

If they are linked to a triple or quadruple, whether as pre-evaporator or as a fourth or fifth body, as great an economy will be reached as can be expected.

Another improvement lately introduced is the utilization of the vapours which are produced by vacuum pans. **Prache** and **Bouillon** have constructed heaters, combined with vacuum pans, which utilize the calories of the vapour. This will no doubt represent an economy, as those calories heating the thick-juice* which is about to enter the pan are used twice.

The same firm has introduced thermo-compressors which compress steam of evaporator bodies of low pressure into higher pressure, in order to re-introduce this compound steam into the steam-drum again.

---

* Or thin-juice for the evaporators.

RITTINGER[*] first proposed this plan in 1857, and PICCARD and WEIBEL tried it for the first time in sugar factories at Pohrlit[†] and Elsdorf. In theory[†] this is profitable, but whether the practical results justify the complication of the evaporation plant further experiments will have to show.

Recently a theoretical demonstration of the economy which may be reached was published.[‡]

According to the inventors[§] it is possible, if 1 kg. of steam at 6 atmospheres (88 lbs. to sq. in.) is available, to raise:—

0·9 kg. of steam of 268 mm. vacuum to steam of 0 pressure.
2 ,, ,, 268 ,, ,, ,, 150 mm. vacuum.
2·58 ,, ,, 0 pressure ,, 157 ,, pressure.
1·20 ,, ,, 0 ,, ,, 330 ,, ,,

Taking the first, where 1 kg. of steam of 6 atm. serves to raise the pressure of 0·9 kg. of steam at 268 mm. vacuum (= 0·65 kg. pressure) to a pressure of 1 atm. (14·7 lbs.), it is explained as follows:—

1 kg. of steam of 6 atm. possesses a total heat of 656·5 calories (164° C.)
1 kg. ,, 1 ,, ,, ,, 6·367 ,, (100° C.)
1 kg. ,, of 268 mm. vacuum = 492 mm. pressure = an absolute pressure of 0·65 kg. per sq. metre has a total heat of *633·2 calories* (87·5° C.)

To compress 1 kg. of steam of 0·65 kg. pressure to steam of 1 kg. pressure there need to be absorbed:

(1) 636·7 – 633·2 = *3·5 calories.*

(2) the labour needed to effect the compression, expressed in calories.

In a steam cylinder of 1 sq. metre area and 2·575 metre stroke, the contents will be 2·575 cub. metres, the volume occupied by 1 kg. of steam of 0·65 kg. pressure.

---

[*] *Technisch Tijdschrift*, 1909-10, p. 193.
[†] *Ibid*, p. 202.
[‡] By D. VAN VLIET, of the Technical School, Amsterdam.
[§] *Technisch Tijdschrift*, 1909-10, p. 194, and p. 202.

If the pressure rises from 0·65 to 1 atm., the volume becomes:

$$\frac{2{\cdot}575 \times 1 \times 0{\cdot}65}{1} = 1{\cdot}674 \text{ cub. metres.}$$

The piston must move 2·575 — 1·674 = 0·90 metre, then the pressure will be 1 kg.

If the piston has moved $\frac{1}{4} = \frac{0{\cdot}90}{4} = 0{\cdot}225$ metre, then the pressure is $\frac{0{\cdot}65 \times 2{\cdot}575}{2{\cdot}35} = 0{\cdot}71$. If $\frac{2}{4}$, $\frac{0{\cdot}65 \times 2{\cdot}575}{2{\cdot}125} = 0{\cdot}79$. If $\frac{3}{4}$, $\frac{0{\cdot}65 \times 2{\cdot}575}{1{\cdot}90} = 0{\cdot}89$. If $\frac{4}{4}$, $\frac{0{\cdot}65 \times 2{\cdot}575}{1{\cdot}675} = 1$.

The average pressure during the work effected by the piston will be $\frac{0{\cdot}71 + 0{\cdot}79 + 0{\cdot}89 + 1}{4} = 0{\cdot}85$ kg. per sq. metre.

The surface of the piston is 1 sq. metre = 10,000 sq. centimetres.

The work done will be: 0·90 × 0·85 × 10,000 = 76,500 kg. m. As 1 kg. m. = 425 calories, 76,500 kg. m. represents *18 calories*. Added to the 3·5 calories [see (1) above], we find a total of *21·5 calories*, while 656·5 — 636·7 = 19·8 calories are available. This represents, be it remembered, only the question of heat; in practice other points will rise, to decide which factory trials must be made. D. VAN VLIET comes to the conclusion that 0·9 kg. is certainly too high, and even 0·66 kg. may not be reached owing to the low efficiency of the apparatus.

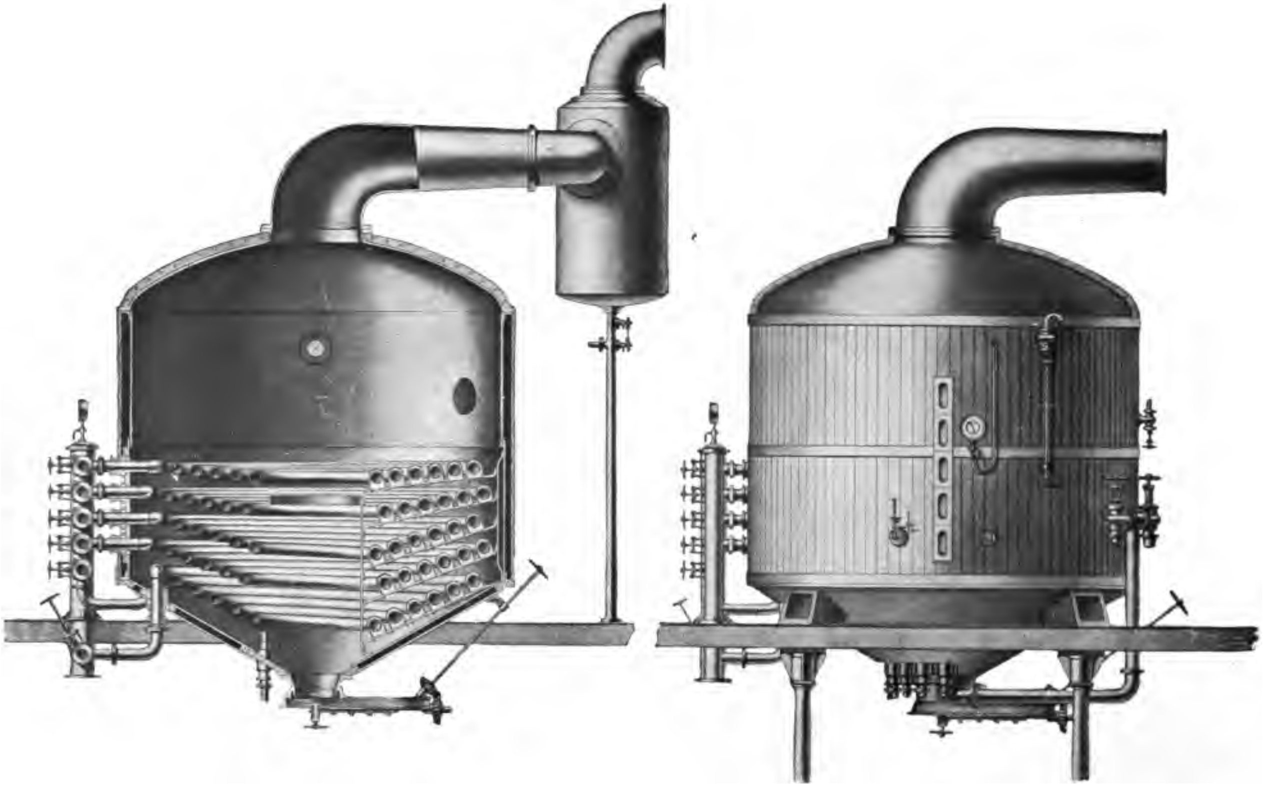


Plate VII.—Type of Low Vacuum Pan, with Coils, as manufactured by Messrs. Werkspoor, Amsterdam, Holland.

CHAPTER IX.

Evaporation and Crystallization in Vacuum Pans.

Historical.—The stages of development of the vacuum pan from an historical standpoint, run on the same lines as those of evaporators, viz., open pans, use of direct fire, substitution of direct fire by steam, and finally, the application of vacuum.

The introduction of vacuum and the use of steam led to (1) more speedy manufacture; (2) saving of fuel; and (3) diminished coloration of the juice, resulting in a greater yield of first-product.

Three methods* were followed to produce the vacuum: those of HOWARD (patented in 1813), of ROTH, and of PELLETAN (patented in 1876). In Howard's pan (see Fig. 1) a vacuum of $\frac{1}{3}$ to $\frac{1}{8}$ atmosphere was created by the aid of air-pumps. The juice was heated by introducing steam into the double bottom of the pan. ROTH added a serpentine for heating, and made the pan communicate with a large cylinder; in this cylinder the vapour from the pan was condensed by means of injected water. Evidently this condenser had to be of large dimensions, as it contained the condensed water from an entire cuite. At the end of the boiling, therefore, the vacuum was bad, which neutralized the gain obtained by the avoidance of an air-pump. It will be noticed that the existing system of to-day is composed of these two factors, air-pump and water injection.

PELLETAN brought into practice another principle, *i.e.*, that of the steam injector, which is used to-day for feeding boilers. Here, however, the steam drew with it the vapours and air produced by the pan into the double bottom of the pan.

---

* See J. J. Reese's "De Suikerhandel van Amsterdam," Part II, p. 81.

Special Requirements and Properties of Vacuum Pans.—Having described the laws and conditions dealing with the first stage of evaporation, which is continuous, and to a large extent automatic in its action, the second stage, involving not only further evaporation but also crystallization, deserves our close attention. The second stage, as already remarked (see page 1), is neither continuous nor automatic, a quantity of thick-juice being dealt with intermittently, and then delivered to a subsequent station in a semi-solid state.

During the time that this quantity of thick-juice is being worked, the operation is again intermittent, and instead of being automatic, a skilled hand has the process constantly under control until the *strike*, as the contents of the pan is called, is dropped into the receptacle beneath, be it crystallizer or centrifugal.

Although the evaporation which goes on in a vacuum pan is essentially the same as that in a multiple effect, there are some points which necessitate a difference in their construction. The main variation of course must be sought in the fact that after multiple evaporation has been carried on as far as is practically possible (for limits see page 31), to the vacuum pan is left the task of concentrating at single effect still further until crystallization is effected. From this point onwards the mass is semi-liquid, and when the concentration has been increased as far as possible the pan is emptied in order to receive a new charge of thick-juice.

While the chief desideratum in the evaporation is that of economy (depending on how the units of the set are put together), and capacity per unit of heating surface (based on fulfilling every possible condition which will favour the transmission of heat), as regards vacuum pans there are other factors which are equally important.

Here the question of tripling or quadrupling, etc., of course does not exist, nor does that of drawing off extra steam. But the utilization of the vapour for heating purposes has been tried by PRACHE and BOUILLON, and this certainly means an economy.

The quantities of water which must be evaporated are discussed in a previous chapter (see page 33); and, recapitulating these, we find:

To evaporate.	Beet Factory.			Cane Factory (Defecation Process).		
At multiple effect..	100	per cent.	....	68	per cent.	
At single effect....	—	,,	....	—	,,	
In the vacuum pan..	8·5	,,	....	8·5	,,	
In the syrup pan..	2·5	,,	....	2·5	,,	
Total.. ..	111	,,	on roots.	79	,,	on cane.

As the boiling of a syrup is irregular, we can safely omit this 2·5 per cent. when considering its latent heat for heating juice. Of the 8·5 per cent. steam which we obtain from the vacuum pan, it cannot be said that the supply is very regular; from the time of concentrating the thin-juice up to graining, ebullition is brisk and the largest part of the water is evaporated within a very short space of time. Very probably this has been the reason why the vapours of the vacuum pan have hitherto been allowed to go to waste, although the temperature is higher than that of the vapour from the last body in a multiple set.

On the other hand, there is a difference in regard to the steam which must be used as the heating agent. The great velocity of the juice in modern climbing film bodies has opened up the possibility of using steam of a fairly high temperature in the multiple effect without danger of caramelization. In vacuum pans, in the beginning of the strike, a high temperature of say 120° C. (248° F.) possibly would do little harm, but with increasing density the viscosity rises and the circulation becomes slower and slower; the danger of sugar being caramelized is certainly not imaginary, and the heating surface must transmit a maximum amount of heat with steam of a lower temperature, say 115° C. (239° F.) at the highest. When Pauly pans or Kestner pre-evaporators are used, the vacuum pans are destined to receive steam of comparatively low pressure which must be fully used in order to reach the economy intended. In a vacuum pan destined to boil raw sugar, however, a slight colouring will not be so troublesome as is the case where granulated or direct consumption sugar is made. In general, we may state that the average temperature of the steam supplied to a vacuum pan is 100° C. to 120° C. (212° to 248° F.)

The graining itself certainly constitutes a difference from the bodies in an evaporation set, but it cannot be said that any special construction is needed, except a handy sampler or "proof stick," and clear glasses through which we can see and watch the contents of the pan. The author has effected graining in pans of very widely differing types, and can say that provided the transmission of heat is not hindered in any way, (*e.g.*, by accumulated non-conducting water or gas), the difference in construction in no way interferes with the formation of a sharp regular grain.

Once the grain is formed, circulation becomes increasingly slower until at the period of stiffening the strike the entire contents of the pan scarcely moves. Different contrivances have been devised whose object is to improve circulation in this semi-solid mass. Screws and spiral arms of different designs are met with, also steam and air-injectors. Of all these contrivances compressed air is probably the best, although the author has made strikes of 96° Brix without the aid of any stirring appliances.

The necessity for emptying the pan periodically has resulted in the evolution of a somewhat different shape as far as the lower part is concerned.

In recording the process of a strike by means of a series of Brix determinations, the following items are worth quoting, as they bring forward what differences there may be as compared with the bodies of an evaporating apparatus:

Stage of the Operation.	Brix.	Polarization.	Purity.	Temperature in Pan. °C.	Temperature of Steam. °C.	Coefficient of Supersaturation.
1. The thick-juice is being concentrated	68·01	62·37	91·7	75	106 to 133	
2. Graining point ..	85·47	78·10	91·3	79	100 to 104	$\dfrac{\dfrac{78\cdot10}{100-85\cdot47}}{3\cdot57}=1\cdot5$
Graining further .	86·48	79·09	91·4	85	—	
3. Grain is strong enough to stand syrup being drawn in.. ..	87·20	75·13	86·1	85	—	
Ditto	86·88	75·35	86·7	85	115 to 125	
After syrup is drawn in	87·68	74·80	85·3	85	—	
4. The semi-solid mass is stiffened further	94·22	84·7	89·8	84	100	
5. The strike is discharged.						

In the first period evaporation pure and simple is going on at single effect. This is continued until the juice reaches a point where more sugar is dissolved in a given quantity of water than a solution of sugar at that temperature holds under ordinary circumstances. This point of supersaturation lies higher for beet juices than for cane juices, and it is not a constant, as is shown by the following coefficients* from BRUNINGS:

Pan.	Temperature at graining. °C.	Point of supersaturation.
Lenze-Freitag	89	1·29 raw sugar.
,, ...	92	1·30 ,,
,, ...	88	1·42 ,,
Greiner	78	1·29 ,,
Coils	76	1·74 granulated.

---

* *Suikerindustrie*, 1909, p. 335.

As it took forty minutes to bring the juice from its original Brix, 62·0 to 85·47, it is evident that the greatest quantity of steam is needed at this period. The second period, during which the grain is formed, usually by drawing in suddenly some cold thick-juice, does not offer any scope for remarks as regards the construction; it is the skill of the operator that comes most into play. The third period, the drawing in of syrup is a resort to extend the boiling of the strike still further; it also offers to the sugar particles the chance to move and to adhere to the grains which have been already formed.

The semi-solid state which the contents has gradually attained is contrary to the essentials of a good circulation. And without circulation the transfer of heat is an impossibility. Some interesting experiments by Miller,[*] dealing with circulation during boiling, have shown that the difference in temperature in a vacuum pan which effects circulation is very small, 1·1734° F. (0·65° C.). Evidently the steam bubbles, which are generated, themselves serve to favour circulation. Additional agitation, however, preferably with compressed air, or else by steam or spiral, will help the process.

The influence of agitation by means of steam has been studied by Mintz.[†] A final molasses of 1·32 sp. gr. was boiled in a copper cylinder, 2 metres high and 100 mm. in diam. It was heated in a brine bath having a temperature of 130° C. (266° F.).

The difference in temperature in the top and the bottom of the cylinder before and after agitation by blowing in steam is clearly shown below:

Before.	After.
2·4	1·0
2·0	1·0
2·1	0·9
2·1	0·9
2·2	0·8
2·1	0·9
2·2	1·0

Analysis of the Molasses.

Brix.		Purity.	
Before.	After.	Before.	After.
66·4	69·2	66·60	66·64

Mintz concludes from his experiments that energetic boiling is best attained in a high and narrow column, as evidently the steam bubbles which are generated produce a much needed circulation, while in low wide pans the action of the bubbles only causes surface waves. This bears out the general opinion that the high narrow Freitag pans (see Plate VIII) do excellent work.

---

[*] *Technisch Tijdschrift*, 1909, p. 205.

[†] *Ibid*, p. 207.

The fourth period, "serrer," or stiffening the cuite, has for its object to obtain a maximum yield of crystals and in consequence a syrup of as low a purity as possible; here an improved circulation will be specially beneficial, so as to reach as high a Brix as possible with a minimum difference of temperature.

For discharging the strike the bottom of the pan is always constructed somewhat tapered. The older types which emptied the strike into small wagons or tanks, and those pans which empty into open crystallizers, have large openings closed by a sliding door. The small tanks from which the hardened massecuite was transferred to a pug-mill, however, belong to the past; and crystallizers to which is left the task of further exhausting the mother-liquor, at the same time keeping the massecuite liquid, have rapidly taken their place. The closed crystallizer is connected with the vacuum pan, and by exhausting the crystallizer and applying pressure in the vacuum pan, a rapid discharge is effected. In order to facilitate the flow of the massecuite, syrup is drawn in after "stiffening."

As regards the general construction of the pan, the following points may be noted: The round type, low and flat, often entirely constructed of copper, has disappeared and a more normal type of pan, higher and larger, constructed of iron has taken its place.

Copper pans are still met with in refineries,* but the necessity for this costly material can hardly be defended except as a fine piece of workmanship, which naturally will do excellent service.

The question of coloration by iron compounds cannot weigh very seriously. It is true that in a sugar factory which has been standing idle during nine months, the first three or four strikes are "off colour," and that this grey and dull tint is caused by the iron rust from pan and pipes. But these strikes are usually remelted and filtered once more. Besides, the pans can be cleaned before boiling is commenced. In a refinery where the pans do not stand idle rust does not occur so easily.

---

* See *International Sugar Journal*, 1913, p. 73, where an illustration is given of a copper pan recently shipped to a Canadian refinery; 15 tons of copper and brass were used in its construction. The dimensions were 22 ft. high and 13 ft. diam.

In what concerns the sizes of modern pans, **Greiner**, and after him **Freitag** (see Plate VIII), have constructed vessels 6 to 7 metres (20 to 23 feet) high with a diameter of 3 to 3½ metres (10 to 11½ feet). Of this height 4½ to 5 metres (14½ to 16 feet) must be considered as destined to be filled with massecuite, leaving some 1½ to 2 metres of space for the vapour when the strike is finished. The pressure in the lower parts of this high column of massecuite is considerable. Taking the specific gravity as 1·45, the pressure of a column of 6 metres (19½ feet) is calculated as follows: A column of 1 sq. cm. in diameter of massecuite takes up a space of 600 cm. × 1 sq. cm. = 0·6 cub. dm. = 0·6 litre. This weight will be 0·6 per 1 sq. cm. × 1·45 × 1 kg. = 0·87 kg. The pressure is thus 0·87 atmosphere or say 12½ lbs. per sq. inch.

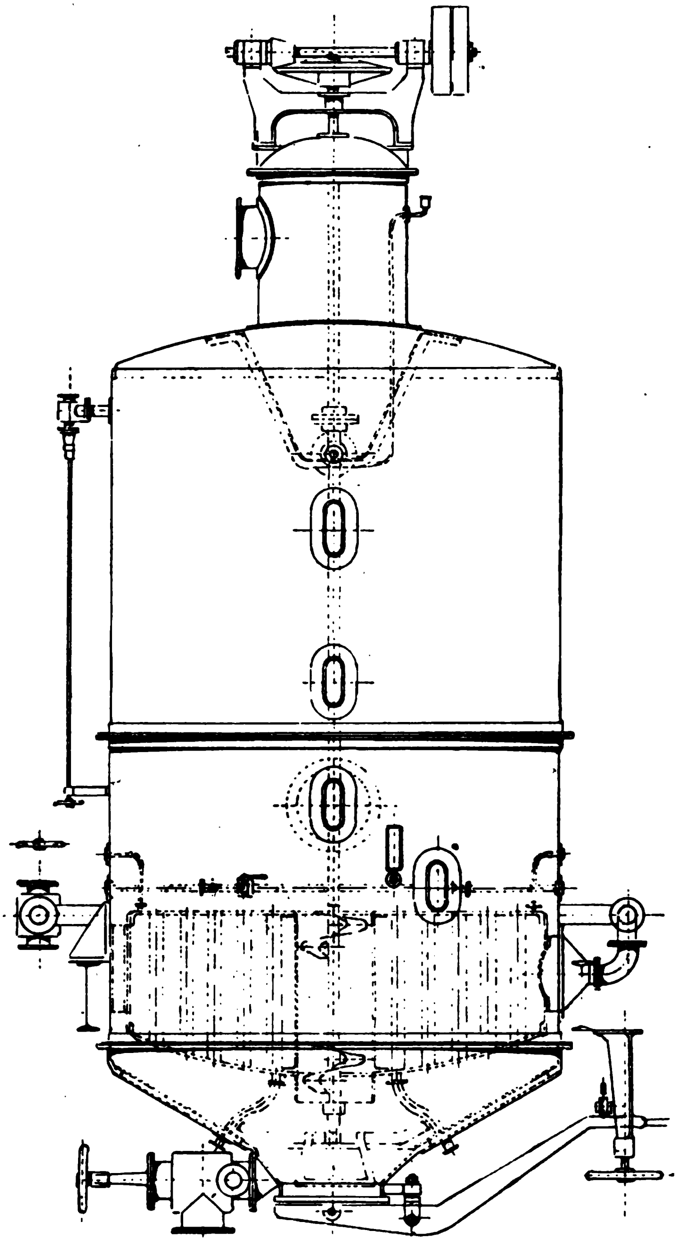
Practice, however, proves that this pressure does not hinder excellent work.

The vital part of a vacuum pan, the steam chamber, has also undergone a change. In the old days no other than copper coils were made, laid in series one above the other. Each coil needed a separate contrivance to discharge the condensed water, and the combination of coils was held together by iron bands and stays. For small pans this system worked fairly well, but for larger ones the length of the coils was impracticable, and they were replaced by ordinary tubes united in sets, as is done in the bodies of an evaporation apparatus. **Greiner** first produced this improvement in 1881, and since then others have followed his lead.

The advantages of having steam-drums above coils is clear. The condensed water which is formed in a steam coil, and increasingly towards the end, renders inactive a part of the heating surface. In order to remedy this, several coils are inserted, the whole being a very intricate apparatus. This complication makes itself felt by the many valves which must be handled and the many traps which must be looked after. As long as the coils are new, no trouble is encountered, but when repairs are made, the steam-drum with its simple tubes is far preferable as regards simplicity.

Steam-drums make it possible to utilize steam from the Pauly or other pre-evaporators. The condensed water is rapidly discharged, and pipes can be suitably fitted in order to draw off the incondensible gases.

PLATE VIII.



Freitag Vacuum Pan with Vertical Tubes and Massecuite Stirrer.

Of its height and its place in the pan, it may be said that it should be constructed so low that still sufficient room is left for a man to do repair work underneath. The pipes chosen are say 3 feet (1 metre) high, their diameter being 4 inches (100 mm.), which is wide enough to give a passage to the massecuite. Some constructors make the steam-drum at an angle, but their reason that the massecuite should not be left behind on the hot tube-plate has not much value, since the pan must be thoroughly steamed out whenever a charge is let down. The bottom is often made double in order that it will also transmit heat and thus favour circulation; this is not, however, absolutely necessary.

As regards transmission, the following may be said. In general for any type of steam vessel, be it coils or tubes, vertical or horizontal, the same laws prevail which hold good in the bodies of evaporation apparatus. Thus the first essential condition, the withdrawal of water and incondensible gases must be properly provided for. Even if only live steam be used, suitable pipes with cocks must draw off the carbonic acid gas, as is shown by M. G. HUMMELINCK.* The water is best drained in vertical tube-drums. As we have already said in regard to types of steam-drums, coils get filled up with water towards the end, and if made very long only a part of them will be in action, unless steam of fairly high pressure be used, *i.e.*, 140° to 150° C. (284° to 302° F.) To remedy this fault and transmit enough heat, a series of coils is constructed, which finally makes a rather complicated whirling mass, offering no end of trouble when a leak has to be located or repairs must be effected. Besides, each coil must be manipulated by a valve and the trap controlled. They are thus costly affairs, as they represent fine workmanship, executed in copper.

In tube-drums more heating surface can be brought into contact with the juice, consequently steam of lower pressure can be utilized, say 100° to 120° C. (212° to 248° F.). In modern installations, *e.g.*, in beet factories, where a pre-evaporator is installed, the steam of this generator at a temperature of 110° to 120° C. (230° to 248° F.) goes to the vacuum pans.

Air and water can be removed quickly and completely, and defects can be easily detected and repaired. The material of the tubes is seamless steel, which is cheaper than copper.

---

* See *De Suikerindustrie*, 1910, p. 172.

As may be expected with a fluid and semi-fluid mass like the contents of a vacuum pan, the transmission of heat is slow, especially towards the end when circulation becomes gradually less.

In the last body of an evaporation set, the coefficient of transmission is not any higher than 10 to 11,* while the difference in temperature is 20° C. (68° F.) to 24° C. (77° F.); thus the calories transmitted per minute and per sq. metre are 200 to 264 (800 to 1056 B.T.U.)

In the vacuum pan the thick-juice boils more violently in the period of concentration than it does in the last body, because the difference in temperature is greater; the temperature of the juice is higher, and the circulation is better. The highest coefficients therefore are found in that period, being fixed by CLAASSEN at 18† (raw sugar), and by LANGEN at 29·6‡ (granulated). We cannot expect a constant, as the temperature of the steam varies within wide limits.

During graining, and further on during warming and finishing, the transmission sinks gradually. The viscosity rises and the circulation gets smaller. Thus CLAASSEN takes the figures for transmission as 10§ during graining and as 3·7 ‖ during the last period.

The nature of the juice, whether pure thick-juice or whether syrup is added, will have its influence as well; the more viscous, the less the transmission. Thus granulated strikes will show a difference from raw sugar strikes. The difference in temperatures varies also. During the strike mentioned above, which was made in a pan provided with coils, the following differences in degrees Centigrade were noted:

During concentration	119	—	75	=	44	
During graining	102	—	79	=	23	
After graining	102	—	85	=	17	
Drawing in syrup	120	—	85	=	35	
Finishing	100	—	84	=	16	
Average					27	(80° F.)

If we take 25° C. to 30° C. (77° to 86° F.) as a normal average difference, the coefficient of transmission will not be any higher than 8 to 9 (1·6 to 1·8 British).

If we want to calculate the heating surface from this basis, we must remember that the work in the vacuum pan is intermittent.

---

* 2·08 to 2·3 British units.

† 3·7 British units.

‡ 6·1 British units.

§ 2·08 British units.

‖ 0·77 British units.

Thus we will need more space and surface than theoretical calculations will suggest to us. If we divide the strikes over 3 to 4 pans, the steam supply will likewise be more even, and, taking 8 hours for a normal period, there must always be a pan ready to receive thick-juice.

The initial temperature of the thick-juice in beet factories is 50° to 60° C. (122° F. to 140° F.), unless it be reheated. In defecation cane factories where the thick-juice is boiled up and left to settle, the temperature will be higher. If we take 60° C. (140° F.) as an average, 1 kg. of water at this temperature for evaporation into steam of 80° will need: $606{\cdot}5 + 0{\cdot}3 \times 80 - 60 = 570$ calories which must be transmitted.

For a capacity of 1,000,000 kg. of beets this would mean :

$$\frac{7 \times 8{\cdot}5 \times 570}{8 \times 25} = 169$$ sq. metres (1818 sq. feet) of heating surface.

In practice, however, 260 to 300 sq. metres (2797 to 3228 sq. feet) divided over three to four pans give good results.*

Usually the capacity of pans is expressed as so many hectolitres or gallons of massecuite, by which must be understood the quantity of massecuite which the pan will hold when a strike is finished. Thus it does not represent the actual content of the pan but only a fraction of it. Taking the average minima which we mentioned before, the pan capacity may be calculated thus, allowing time for emptying and leaving space for emergencies.

Dividing the cuites over three pans, averaging five strikes per 24 hours, in a 1000-metric ton factory, the capacity will be :—

	In Beet Factories.	Defecation Cane Factories.
Massecuite I	16 per cent. ..	14 per cent.
Of specific gravity, 1·45	11 litres per cent...	9·6 litres per cent
First massecuite per 24 hours ..	1100 H.L. .. (24,200 gallons.)	960 H.L. (21,120 gallons.)
H.L. per strike contents of pan ..	220 H.L. .. (4840 gallons.)	192 H.L. (4224 gallons.)
Heating surface of each pan ..	100 sq. metres .. (1071 sq. feet.)	100 sq. metres. (1071 sq. feet.)

These represent minimum values, fluctuating according to the process followed, the temperature of steam used, and the type of pan.

---

* STIFT and GREDINGER take as a practical basis 16 kg. of water per hour and per sq. metre ; this would mean $\frac{417 \times 8{\cdot}5}{16} = 221$ sq. metres (2378 sq. feet).

If the thick-juice entered the pans with a lower Brix, the heating surface will be proportionally larger; if granulated is manufactured, and remelted brown sugar is also drawn into the pan, the surface will be three to four times as large; if steam of low temperature must be used, the surface will also be larger. In regard to the types of vacuum pans in use, the horizontal one is extensively employed with the vertical, especially in Austria. They present some difficulty in emptying, but, on the whole, their merits compared with vertical pans are probably equal.

Before finishing our chapter, some points may be summarized which should be kept in view, when a vacuum apparatus is planned or ordered.

(*a*) The type which is gradually winning its way is a cylinder whose diameter is at least half the height. Bottom and dome are additional to this cylinder.

(*b*) The transmission of heat in such pans is best effected in a single steam-drum, with vertical steam tubes, at least 4 inches (100 mm.) with one or more larger tubes of 24 to 27 inches (600 to 700 mm.).

(*c*) Both the draining of water and expelling of incondensible gases must be provided for in an efficient manner.

(*d*) Double bottoms are beneficial, but not strictly necessary; stirring devices, especially when worked by compressed air, are advantageous, but not absolutely indispensable either.

(*e*) As to outlets and connections with the crystallizers, the closed system is generally preferred, as it allows speedy emptying by means of a small opening.

(*f*) The use of copper, except for fittings, is no longer of great importance; bodies are constructed of cast-iron, the tubes of seamless steel, and the tube-plates of wrought-iron.

For the condensing of the vapours which are produced during boiling, connection with a central condenser represents an economy over the system of providing each vacuum pan with a separate air pump. The pan boilers claim that these latter can produce better

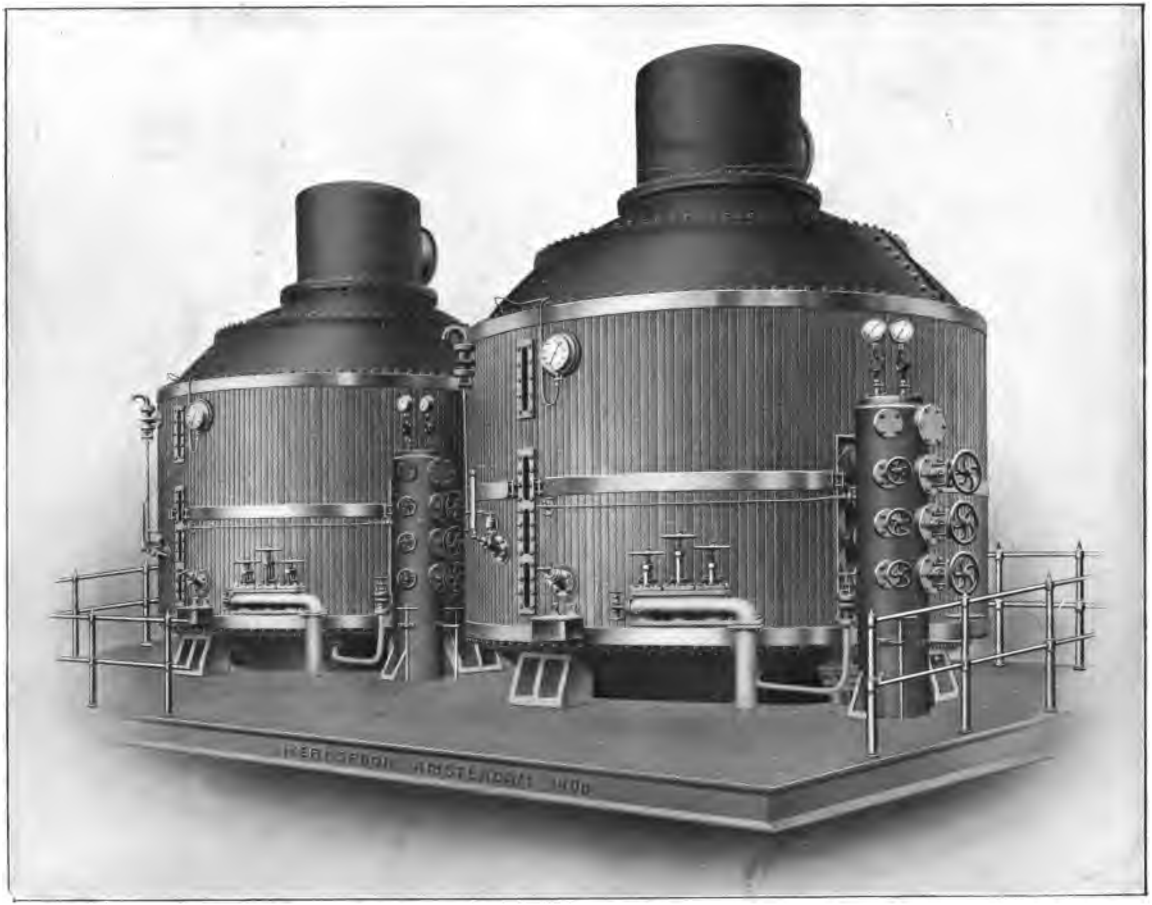


Plate IX.—Type of Low Vacuum Pan, with Coils and Wood Casing, as manufactured by Messrs. Werkspoor, Amsterdam, Holland, for a Java Cane Sugar Factory.

strikes, but this claim does not hold good as is proved by the many factories which use a central condenser.

In concluding this treatise, some remarks regarding the future may be offered.

Mutual competition produces a steady improvement of existing industrial installations, as we remarked at the outset. However, in sugar factories the task of the man who has charge of the technical part of the business is often a very unthankful one indeed. In beet as well as in cane factories the preponderance of the commercial side is so overwhelming that even if the result means a saving of some odd thousand pounds, this does not count much if it is compared with the rise in price amounting to a few cents per lb. of a campaign output of say ten million kg. of sugar! On the other hand, the benefit of the technical advancement is everlasting, while the rise in price may be followed by a decline. Nevertheless it is in every way a desideratum to maintain progress, and every technical supervisor who has his heart in his work cannot help devising improvements in the installation which is entrusted to his charge.

Even in beet factories there is still ample scope for these reforms, as many factories by using far too much coal show clearly.

Among cane factories, many still do not manage with their bagasse alone but have to supplement it with coal or wood. In studying alterations in this direction, the chemical side of the question should never be overlooked. Thus when granulated is produced, we must exclude every factor which may impart a dark colour to the grain, and any too close imitation of the beet installation must be guarded against, as cane juice cannot stand what beet juice can. In future systems of evaporation the climbing film will no doubt take a prominent place, as it makes evaporation under pressure possible, and thus the extension of the available difference in temperature of initial steam and vapour of the last body.

TABLES.

Table of Steam.

Temperature, °C.	Pressure, kg. per sq. centimetre.	Pressure, mm. mercury.	Vacuum, mm. mercury.	Volume of 1 kg. of steam, cub. m.	Weight of 1 cub. m. of steam, kg.
0	0·0063	4·6	755·4	204·97	0·00488
50	0·125	92·0	668·0	12·091	0·08271
55	0·160	117·5	642·5	9·607	0·10409
60	0·202	148·8	611·2	7·695	0·12995
65	0·254	186·9	573·1	6·211	0·16100
70	0·317	233·1	526·9	5·050	0·19800
75	0·392	288·5	471·5	4·1353	0·2418
80	0·482	354·6	405·4	3·4085	0·2934
85	0·589	433·0	327·0	2·8272	0·3537
90	0·714	525·4	234·6	2·3592	0·4239
95	0·862	633·7	126·3	1·9797	0·5051
100	1·033	760·0	—	1·6702	0·5987
105	1·232	906·0	—	1·4166	0·7059
110	1·462	1075·0	—	1·2073	0·8283
115	1·726	1269·0	—	1·0338	0·9673
120	2·027	1491·0	—	0·8894	1·1243
125	2·371	1744·0	—	0·7681	1·3018
130	2·760	2030·0	—	0·6664	1·5005
135	3·200	2354·0	—	0·5800	1·7241

Table giving the Properties of Saturated Steam.

Inches of Vacuum	Temperature, deg. F.	Absolute pressure, lbs. per sq. ins.	Volume, cub. ft. lb.	Weight, per cub. ft.	Inches of Vacuum	Temperature, deg. F.	Absolute pressure, lbs. per sq. ins.	Volume, cub. ft. lb.	Weight, per cub. ft.
0	212·0	14·7	26·6	0·0376	15	178·96	7·33	50·3	0·0199
½	211·15	14·25	26·9	0·0372	15½	177·44	7·08	52·0	0·0192
1	210·29	14·21	27·3	0·0366	16	175·87	6·84	53·8	0·0186
1½	209·42	13·16	27·7	0·0361	16½	174·26	6·6	55·7	0·0179
2	208·54	13·72	28·1	0·0356	17	172·59	6·35	58·1	0·0172
2½	207·64	13·47	28·5	0·035	17½	170·86	6·1	60·6	0·0165
3	206·73	13·22	29·0	0·0344	18	169·07	5·86	63·0	0·0159
3½	205·8	12·98	29·5	0 0339	18½	167·23	5·61	65·5	0·0153
4	204·86	12·78	30·1	0·0332	19	165·31	5·36	68·2	0·0147
4½	203·91	12·48	30·7	0·0326	19½	163·23	5·12	71·2	0·014
5	202·94	12·24	31·3	0 0319	20	161·35	4·87	75·0	0·0133
5½	201·95	11·99	31·9	0·0314	20½	159·09	4·63	78·5	0·0127
6	200·95	11·75	32·5	0·0308	21	156·85	4·38	83·0	0·012
6½	199·93	11·51	33·1	0·0302	21½	154·48	4·14	87·5	0·0114
7	198·89	11·26	33·7	0·0297	22	151·97	3·9	92·7	0·0108
7½	197·83	11·01	34·4	0·029	22½	149·34	3·76	95·0	0·0105
8	196·75	10·77	35·1	0·0285	23	146·55	3·41	104·0	0·0096
8½	195·65	10·52	35·9	0·0278	23½	143·59	3·16	112·0	0·0089
9	194·53	10·28	36·7	0·0272	24	140·42	2·92	120·5	0·0083
9½	193·39	10·03	37·5	0·0266	24½	137·01	2·67	131·0	0·0076
10	192·23	9·78	38·3	0·0261	25	133·32	2·43	143	0·007
10½	191·03	9·54	39·3	0·0254	25½	129·31	2·17	160	0·0062
11	189·81	9·3	40·4	0·0248	26	124·89	1·93	178·8	0·0056
11½	188·57	9·05	41·4	0·0242	26½	119·94	1·68	203·0	0·0049
12	187·3	8·8	42·5	0·0235	27	114·34	1·44	236·8	0·0042
12½	186·0	8·57	43·6	0·023	27½	107·84	1·19	282·8	0·0035
13	184·66	8·3	44·8	0·0224	28	100·05	0·94	356·6	0·0028
13½	183·29	8·1	46·1	0·0216	28½	90·24	0·69	515·2	0·0019
14	181·88	7·82	47·2	0·0212	29	76·8	0·45	660	0·0015
14½	180·44	7·58	49·0	0·0204	29½	54·21	0·21	833	0·0012

Metric System.

Measures of Length.

1 inch = 2·539954 centimetres. 1 centimetre = 0·3937 inch.
1 foot = 12 inches = 0·30479499 metre. 1 metre = 3·2809 feet.
1 yard = 3 feet = 0·9143835 metre. 1 metre = 1·0936 yards.

Measures of Surface.

1 sq. inch = 6·4514 sq. centimetres. 1 sq. centimetre = 0·1550 sq. inch.
1 sq. foot = 0·09290 sq. metre. 1 sq. metre = 10·7639 sq. feet.
1 sq. yard = 0·8361 sq. metre. 1 sq. metre = 1·19599 sq. yards.

Measures of Capacity.

1 cub. inch = 16·386 cub. centimetres. 1 cub. centimetre = 0·06103 cub. inch.
1 cub. foot = 0·02832 cub. metre. 1 cub. centimetre = 35·3147 cub. feet.
1 cub. yard = 0·07645 cub. metre. 1 cub. metre = 1·3080 cub. yards.

Measures of Weight.

1 pound (lb.) = 16 ozs. = 0·45359265 kilograms. 1 kilogram. = 2·20462 lbs.
1 ton (long) = 20 hundredweight = 1016·047 kilograms.
1 cwt. = 50·802 kilograms. 1000 kilograms. = 0·984206 ton.

Units of Heat.

1 calorie = the heat required to raise the temperature of 1 kilogram of water 1 degree Centigrade.

1 B.T.U. (British Thermal Unit) = the heat required to raise the temperature of 1 lb. of water 1 degree Fahrenheit.

1 calorie = 4 B.T.U.

1 B.T.U. = 0·25 calories.

Units of Pressure and Vacuum.

1 atmosphere = the pressure at sea level of 1·034 kilogram acting on 1 sq. centimetre, or 2·279 × 6·45 = 14·699 lbs. to the sq. inch.

1 lb. per square inch = 0·068 atmosphere.

Units of Transmission of Heat Coefficients.

Metric System.—1 calorie per sq. metre per degree Centigrade difference in temperature in 1 minute.

British System.—1 B.T.U. per sq. foot per degree Fahrenheit difference in 1 minute.

$$\frac{\text{Metric unit}}{\dfrac{0{\cdot}25 \times 9}{0{\cdot}093 \times 5}} = \frac{\text{Metric unit}}{4{\cdot}8} = \text{British unit}$$

$\frac{4}{5}$ c

Thermometer Scales.

Centigrade.	Reaumur.	Fahrenheit.	Centigrade.	Reaumur.	Fahrenheit.
50	40	122	95	76	203
55	44	131	100	80	212
60	48	140	105	84	221
65	52	149	110	88	230
70	56	158	115	92	239
75	60	167	120	96	248
80	64	176	125	100	257
85	68	185	130	104	266
90	72	194			

Variation of the Boiling Point of Sugar Solutions in Degrees Centigrade compared with Water (*Claassen*).

Dry Substance, per cent.	If the purity of the sugar solution be:				
	100	93	83	73	62
5	0·05	0·05	0·05	0·05	0·05
10	0·1	0·1	0·1	0·15	0·2
15	0·2	0·2	0·25	0·25	0·35
20	0·3	0·3	0·35	0·40	0·5
25	0·45	0·45	0·5	0·60	0·75
30	0·6	0·65	0·7	0·85	1·1
35	0·8	0·85	1·0	1·2	1·5
40	1·05	1·15	1·35	1·6	1·95
45	1·4	1·55	1·75	2·1	2·5
50	1·8	2·0	2·25	2·7	3·15
55	2·3	2·6	3·0	3·5	4·0
60	3·0	3·3	3·8	4·5	5·0
65	3·8	4·25	4·8	5·6	6·2
70	5·1	5·4	6·2	7·0	8·0
75	7·0	7·3	8·5	9·2	10·3
80	9·4	10·0	11·4	12·2	13·6
85	13·0	13·4	15·9	16·9	18·2
90	19·6	20·0	22·0	24·7	26·9
92	24·0	—	—	—	—
94	30·5	—	—	—	—

Boiling Point of Sugar (Sucrose) Solutions at Sea Level (Pressure 760 mm.) in Degrees Centigrade.

Sugar (sucrose), per cent. by weight.	Gerlach.	Flourens.	Claassen-Hermann.
10	100·4	100·1	100·1
20	100·6	100·3	100·3
30	101·0	100·6	100·6
40	101·5	101·1	101·05
50	102·0	101·9	101·8
60	103·0	103·1	103·0
70	106·5	105·3	105·1
75	109·0	107·4	107·0
80	112·2	110·4	109·4
85	117·5	114·9	113·0
90	127·0	122·6	119·6
92	—	127·9	123·0

Flourens' Table of the Boiling Point of Saturated Solutions of Pure Sugar (Sucrose).

Vacuum, mm. of mercury.	Boiling point of pure water, degrees Centigrade.	Boiling point of a saturated solution of pure sugar, degrees Centigrade.	Sugar, per cent. by weight in solution.
70·7	40	45·4	70·8
69·13	45	51·0	72·1
67·12	50	56·4	73·2
64·63	55	62·0	74·4
61·53	60	67·7	75·6
57·73	65	73·4	76·8
53·09	70	79·2	78·1
47·49	75	85·0	79·5
40·79	80	90·9	80·8
32·82	85	96·8	81·9
27·82	88	100·0	82·5

THE

SUGAR MACHINERY MANUFACTURING Coy. Ltd.

Telegraphic Address:
"PROOFSTICK," LONDON.

Codes used:
Engineering, Western Union,
A B C, Commercial, A 1.

Head Offices: 76, ELSHAM ROAD,
LONDON, W.

QUADRUPLE EFFET EVAPORATOR, 12,000 Square Feet Heating Surface, in course of erection.

MANUFACTURERS OF ADVANCED
SUGAR MAKING MACHINERY.

COMPLETE CANE SUGAR FACTORIES.

EVAPORATORS.

MULTIPLE EVAPORATORS,
GIVING
HIGHEST EFFICIENCIES.

Managing Director: ROBERT MITCHELL, M.I.Mech.E.

HARVEY ■ ■ ■

ENGINEERING Co., Ltd.

SCOTLAND STREET ENGINE WORKS,

- GLASGOW,

Sugar Machinery Specialists.

MANUFACTURERS OF ■ ■ ■
EVERY DESCRIPTION OF MACHINERY
FOR THE ■ ■ ■

SUGAR INDUSTRY.

COMPLETE - - -

SUGAR FACTORIES

and REFINERIES - - -

EXPERT ADVICE given in connection with the ENLARGING and MODERNIZING of EXISTING PLANT.

ESTIMATES UPON APPLICATION.

HARVEY

ENGINEERING Co., Ltd.,

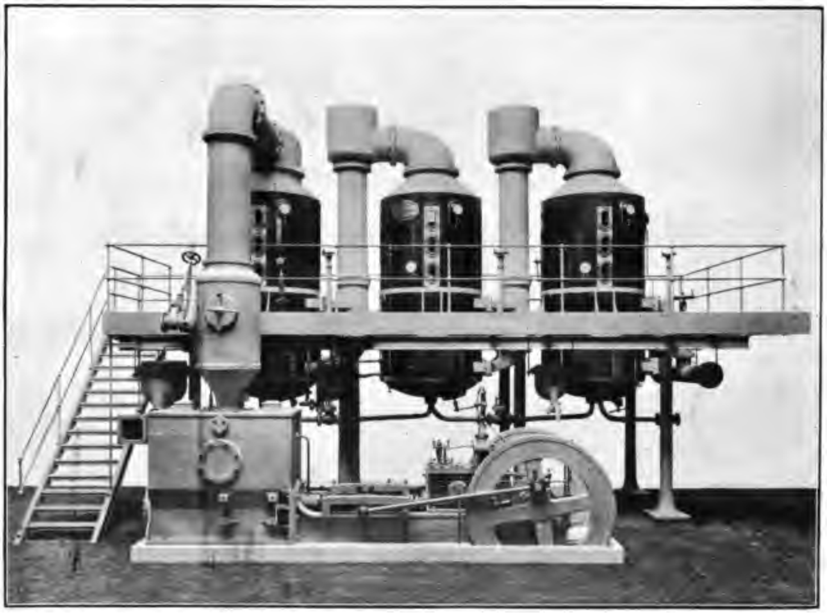
SCOTLAND STREET ENGINE WORKS,

GLASGOW.

MANUFACTURERS OF

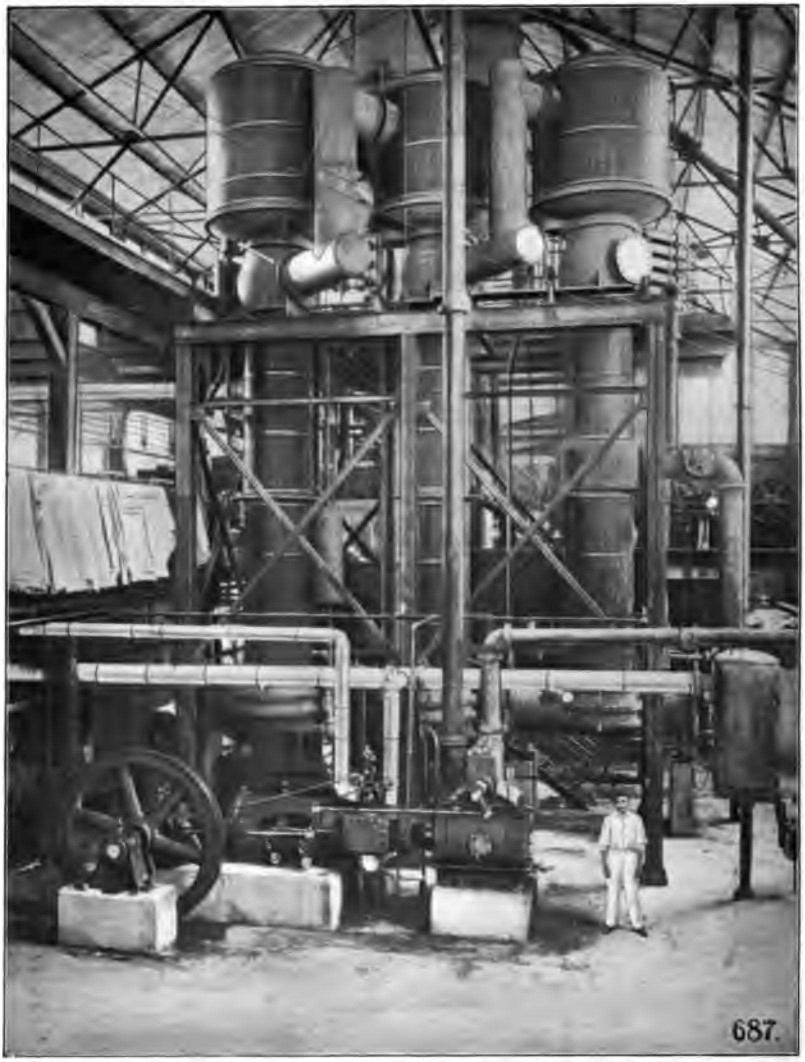
Harvey's Multiple Effet Evaporators

For SUGAR FACTORIES.



WE HAVE NOW SUPPLIED EVAPORATORS
FOR OVER 130 SUGAR ESTATES IN
ALL PARTS OF THE WORLD.

KESTNER Patent EVAPORATOR.



Kestner Triple Effect, working in Sugar Factory.

Some of the advantages of the **KESTNER** system of Evaporation are as follows:—

LESS SCALING;
NO ENTRAINMENT;
BRIGHTER SYRUP;
BETTER SUGAR.

If you wish to increase your present output up to 25 °/ₒ write for particulars of

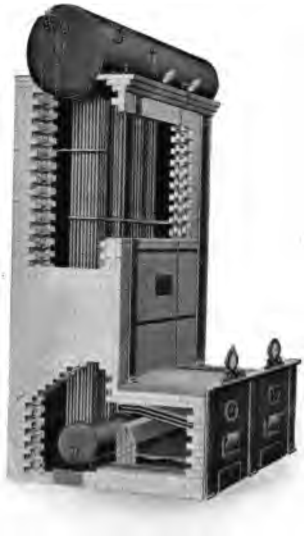
KESTNER PRE-EVAPORATORS.

KESTNER PATENT WATER-TUBE BOILER.

FREEDOM FROM SCALING.

HIGHEST EFFICIENCY IN WORKING, COMBINED WITH SIMPLICITY.

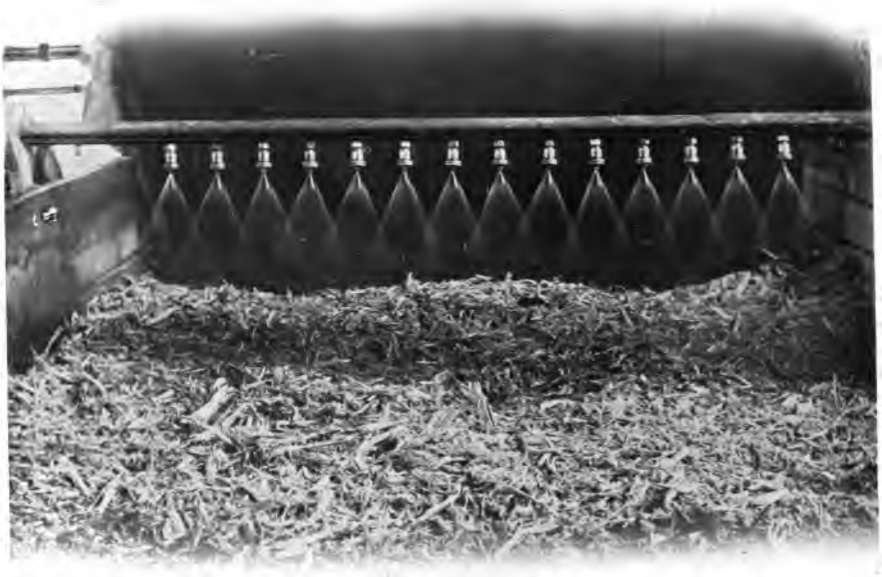
No Softening Plant required.



THE
IDEAL BOILER
FOR BURNING
BAGASSE
AND
SPENT WASTE.

SPECIALLY DESIGNED
for
COLONIAL
Conditions & Transport

KESTNER INJECTORS, FOR IMBIBITION OF BAGASSE.



A Set of "Kestner" Imbibition Jets at work on a Mill.

The "KESTNER" system of Bagasse Imbibition ensures the greatest economy and efficiency and reduces the loss of sugar to a minimum.

For ENGLAND and her COLONIES, apply to

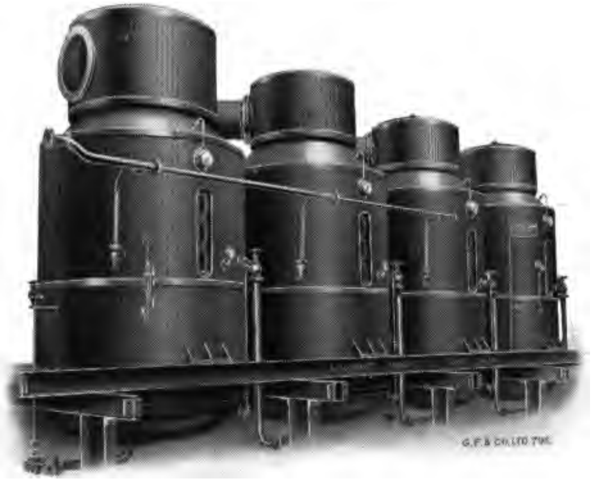
KESTNER EVAPORATOR & ENGINEERING CO., LTD.,
37, PARLIAMENT STREET, WESTMINSTER, LONDON.

For other Countries—

PAUL KESTNER, 7, RUE BE TOUL, LILLE, FRANCE.

GEORGE FLETCHER & CO., LTD.,

DERBY, ENGLAND.



QUADRUPLE
EFFET
EVAPORATOR.

THREE-THROW
FLETCHER-EDWARDS
AIR PUMP.
(STEAM AND ELECTRICALLY DRIVEN.)

SPECIALISTS IN THE
REMODELLING OF **EXISTING FACTORIES**

Telegraphic Addresses:
"AMARILLA, DERBY."
"AMARILLA, LONDON."

LONDON OFFICE:
21, MINCING LANE, E.C.

ZAREMBA EVAPORATORS

Are built for **Long Life, Hard Service,** and **No Worry** to their **Owners.**

ANY SIZE ANY LIQUID.

- Cane Sugar,
- Beet Sugar,
- Glucose,
- Milk Sugar,
- Beef Extract.
- Glue,
- Glycerin,
- Tankwater,

- Black Liquor (Pulp Mills),
- Caustic Soda,
- Distillery Slop,
- Steepwater,
- Pickle-water (Iron sulphate),
- By-products of all kinds.

The Zaremba Patent Evaporator.

Cylindrical Shells of cast-iron, steel or copper.
Horizontal Tubes (steam inside) readily removable.
Vigorous circulation and maximum heat transmission.
No moving parts; no complications.
No Tube-vents to become clogged.
Readily operated by cheap labour.
Density of liquor under perfect control.
Every feature thoroughly tested by long experience.

SPECIAL TYPES FURNISHED FOR SPECIAL WORK.

The MANTIUS CRYSTALLIZING EVAPORATOR
for liquids precipitating crystals—
SPENT LYE, ELECTROLYTIC CAUSTIC, SALT MANUFACTURING, etc.

The RAPID CIRCULATION EVAPORATOR
For foaming and scale-forming liquids—
MILK WHEY, RESINOUS LIQUIDS, WATER DISTILLATION.

The MANTIUS HIGH CONCENTRATOR
Concentrating to extra high density, 80-90 per cent. solids—
CAUSTIC SODA, TANNING EXTRACT.

CAUSTICIZING APPARATUS
Operating on **Continuous System** and under **Pressure,** economically producing strong solutions under perfect control.

The Mantius Crystallizing Evaporator.

ZAREMBA COMPANY,
Morgan Building, BUFFALO, U.S.A.

FAWCETT, PRESTON & CO., Ltd.,

Engineers, LIVERPOOL.

Telegraphic Address: "FAWCETT, LIVERPOOL."
Codes used : A B C (4th and 5th Editions), A 1,
and Western Union.

MANUFACTURERS OF

EVAPORATING AND ALL OTHER CLASSES OF MACHINERY FOR THE COMPLETE EQUIPMENT OF

SUGAR FACTORIES

The above illustrations are from photographs taken in the Shops of

FAWCETT, PRESTON & CO., Ltd.

THE

International Sugar Journal

With which is incorporated THE SUGAR CANE (1869-1898),

A monthly Journal for ALL interested in the Sugar Industry.

THE LEADING TECHNICAL JOURNAL

OF THE

SUGAR WORLD.

SPECIAL FEATURES:—

(1) **Valuable Original Articles** on general matters, especially white sugar manufacture, by men recognized as foremost in their respective subjects.

(2) **A complete Review of Current Technical Literature,** in as clear and simple language as possible.

(3) **Interesting Translations of Articles** by the leading foreign experts, from Dutch, German, and French contemporaries.

(4) **Reviews of New Books,** on technical and non-technical subjects, by British, American, German, Dutch, and French authors.

(5) **Summaries of Patents,** British, American, German, Dutch, and French.

(6) **Editorial Comments,** on political, statistical, and technical matters.

(7) **Leading Articles** on aspects of the cane and beet sugar industries; and

(8) **Statistics,** relating to Great Britain, America, Germany, Austria, Russia, France, Holland, Cuba, Hawaii, Java, the West Indies, and other countries.

Publishing Offices:

2, ST. DUNSTAN'S HILL, LONDON, E.C., England.

Subscription, 12/- ($3·00) per annum, post free.

Published on the 12th of the month.

WRITE FOR A FREE SPECIMEN COPY.

BOOKS ON SUGAR, AND ITS
MANUFACTURE, PUBLISHED BY
NORMAN RODGER, . . .
2, ST. DUNSTAN'S HILL, ...
LONDON, E.C.

The Book of the Moment for SUGAR MANUFACTURERS.

JUST PUBLISHED.

PLANTATION
WHITE SUGAR MANUFACTURE.

BY
W. H. TH. HARLOFF,
MANAGER OF THE BOEDOERAN SUGAR FACTORY, JAVA,
AND
H. SCHMIDT,
CONSULTING SUGAR CHEMIST AND ENGINEER, JAVA.

TRANSLATED FROM THE SECOND REVISED DUTCH EDITION, BY
JAMES P. OGILVIE, F.C.S.,
TECHNICAL EDITOR OF THE "INTERNATIONAL SUGAR JOURNAL."

7s. 6d. net.

Post Free { Inland, 7s. 10d.
Abroad, 8s. (or $2.00).

BOOKS on SUGAR AND ITS MANUFACTURE Published by NORMAN RODGER,
2, St. Dunstan's Hill, LONDON, E.C.—Continued.

By **H. C. PRINSEN GEERLIGS** (Late Director of the West Java Sugar Experiment Station):

THE WORLD'S CANE SUGAR INDUSTRY—PAST AND PRESENT.

(The English Version of Mr. Geerligs' "De Rietsuikerindustrie in de verschillende Landen van Productie," being Part IV. of the Java Sugar Manufacturers' Association Handbooks on the Production and Manufacture of Sugar). An historical, technical and statistical Review of the Cane Sugar Industry throughout the World. About 400 pp. Super Royal 8vo. Bound in cloth. **12s.** net. Postage extra.

CANE SUGAR AND ITS MANUFACTURE: An amplification of this author's earlier Work, **"On Cane Sugar and the Process of its Manufacture in Java,"** published in 1903, but brought up to date and extending to 352 pages, of which four-fifths is entirely new matter. 352 pp. Super Royal 8vo. Price **12s.** net. Postage, 5d. Inland; 1s. Abroad, extra.

METHODS OF CHEMICAL CONTROL IN CANE SUGAR FACTORIES.

An invaluable Handbook for Sugar Chemists and Manufacturers. Cloth. 86 pp. Royal 8vo. **3s. 6d.** net. Postage extra: 4d. Inland, 6d.. Abroad.

CANE SUGAR: A Text-Book on the Agriculture of the Sugar Cane, the Manufacture of Cane Sugar, and the Analysis of Sugar House Products, together with a Chapter on the Fermentation of Molasses. By **NÖEL DEERR,** Sugar Technologist at the Experiment Station of the Hawaiian Sugar Planters' Association; Author of **"Sugar and the Sugar Cane."** 592 pp. Royal 8vo., with 22 plates (11 coloured), and 240 other illustrations. **The finest and most up-to-date work on the cane sugar industry yet issued to the public.** Price **20s.** net ($5). Postage, 6d. Inland; 1s. 4d. Abroad, extra.

SCIENCE IN SUGAR PRODUCTION: An Introduction to the Methods of Chemical Control. By **T. H. P. HERIOT.** Royal 8vo., 104 pp. **6s.** net. Postage 6d. extra, Abroad; 4d. extra, Inland.

TWO WALL CHARTS FOR SUGAR CHEMISTS.

(Mounted on Cloth and ready for hanging.)

I. Table for finding the Sucrose Content of Juices, clarified with 10% of Subacetate of Lead from the Specific Gravity of the Original Juice, and the Readings in a Schmidt and Haensch Polariscope when observed in a 200 mm. tube.

II. Tables for the Correction of the Brix Hydrometer at different Temperatures. (*a*) When the Hydrometer is tested at 84° F.
(*b*) When the Hydrometer is tested at 17·5° C.

Price **5s.** net for the two, or **3s.** net for either. Postage, 4d. extra.

BOOKS on SUGAR AND ITS MANUFACTURE Published by NORMAN RODGER,
2, St. Dunstan's Hill, LONDON, E.C.—Continued.

UNIVERSITY OF CALIFORNIA LIBRARY
BERKELEY

Return to desk from which borrowed.
This book is DUE on the last date stamped below.

23Jan'51NW

REC. CIR. JUN 10 76

LD 21-100m-11,'49 (B7146s16) 476

n of the
ith several
l in Sugar
K, F.I.C.,

ACTURE
IGS; fully
rrying out
de of the

For further details see later announcements in
"THE INTERNATIONAL SUGAR JOURNAL."

YC 70386

M510975

TP377
K6

Telegraphic Address:
"MIRRLEES, GLASGOW."

THE

MIRRLEES WATSON CO., Ltd.,

GLASGOW,

SCOTLAND.

MAKERS OF THE MOST MODERN

MACHINERY

FOR THE

MANUFACTURE OF

SUGAR.

HEAD OFFICE & WORKS:

SCOTLAND STREET,
GLASGOW.

LONDON OFFICE:

122, CANNON STREET, E.C.

Telegraphic Codes:—
A B C (4th & 5th Editions),
Western Union,
Engineering,
Lieber's,
A 1.

970,4

A. & W. SMITH & CO., LTD.,

EGLINTON ENGINE WORKS,

GLASGOW.

A & W. SMITH & COMPANY LTD GLASGOW
431.

HIGH EFFICIENCY EVAPORATORS.

ALL KINDS OF

SUGAR MAKING MACHINER